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Sikorsky Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION

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USER'S MANUAL FOR THE

COUPLED MODE VERSION OF THE

NORMAL MODES ROTOR AEROELASTIC ANALYSIS COMPUTER PROGRAM

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TITLE · USER'S MANUAL FOR THE COUPLED MODE VERSION OF THE NORMAL MODES AEROELASTIC ANALYSIS COMPUTER PROGRAM Y210

DOCUMENT NUMBER   SER-50910

PREPARED UNDER   NAS2-6463

DOCUMENT DATE

PERIOD COV' RED

This document is applicable to the following aircraft model(s) and contract(s):

　　　MODEL　　　　　　　　　　　　　CONTRACT

　　　General

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REV	CHANGED BY	REVISED PAGE(S)	ADDED PAGE(S)	DELETED PAGE(S)	DESCRIPTION	DATE	APPROVAL

REVISIONS CONTINUED ON NEXT PAGE

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FOREWORD

This User's Manual has been prepared to provide the engineer with the information required to run the coupled mode version of the Normal Modes Rotor Aeroelastic Analysis Computer Program. The manual provides a full set of instructions for running the program, including calculation of blade modes, calculations of variable induced velocity distribution and the calculation of the time history of the response for either a single blade or a complete rotor with an airframe (the latter with constant inflow). The analysis used is discussed in the technical report, Reference a.

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This guide will answer these three questions. What is the program capable of doing? How, in general terms, is this accomplished. What must the user do to obtain the desired results. The emphasis is on how. The why is described in References a, b, c, d, and e.

WHAT THE PROGRAM DOES

The function of the program may be logically considered in five parts.

The first part calculates the coupled natural frequencies and mode shapes from the blade physical properties and rotor speed. It is possible to stop at this point and run successive cases varying rotor speed or other blade physical properties to investigate blade frequency characteristics.

The second part calculates rotor steady state, air loading, blade bending and rotor generated forces and moments for a specified flight condition and control setting. The program may be stopped at this point and multiple cases run to investigate parametric variations in control positions, blade physical properties, or flight conditions. It also writes data files used in part three.

The third part is the calculation of the variable inflow distribution across the rotor disc. This part requires the blade response for a steady state revolution to provide the necessary input data. The program can run either with constant inflow assumed or with the calculation of variable inflow. This part also generates a data file of induced velocities that is read by the coupled mode dynamic analysis section if induced velocities are to be included in the blade dynamic response.

A full description of this section may be found in Appendix C, including the stand alone option.

The fourth part is the trimming mode. In trim, equilibrium is established for all three orthogonal forces and all three orthogonal moments. It is possible to stop at this point and run successive cases.

The fifth part is the calculation of the aeroelastic transient during a gust encounter. Again successive cases may be run. It is not possible to run variable induced velocity during this mode.

DISCUSSION (cont'd)

HOW IS THIS ACCOMPLISHED

Natural Frequencies and Mode Shapes

The equations for the calculation of coupled flatwise and chordwise natural frequencies and mode shapes are described in Reference b. The equations for torsional frequencies and mode shapes are displayed in Reference a. There are two hinge conditions permitted in the flatwise and the chordwise direction; articulated or nonarticulated. In torsion provision for either a root spring or rigid root attachment has been provided.

Rotor Steady State

The rotor blade modal amplitudes and first derivatives are given at the start of the first revolution of the rotor in the program. These starting values may be assumed zero, be left over from a previous case, or be loaded in via cards. The equations of motion described in Reference c are then employed to calculate the azimuthal time history of the blade motions. Three types of blade airfoil section data may be selected by the user; spar data - univariant function of angle of attack, bivariant function of angle of attack and Mach number, quadravariant function of the angle of attack and its first and second time derivatives, and Mach number.

A reference blade is assumed at zero azimuth with the prescribed starting values. The equations of motion of this blade are integrated around the azimuth from zero to 360 degrees. The procedure used is described in Reference d. At this point the values of modal amplitudes and first derivatives at zero degrees azimuth and 360 degrees azimuth are compared. If the modal amplitudes and first derivatives are within a user specified tolerance the calculation proceeds to the integration of the rotor forces and moments and the calculation of blade bending moments and other output data. If convergence is not obtained, successive revolutions are performed until convergence is obtained or the maximum number of revolutions, as specified by the user, is exceeded. If the number of revolutions is exceeded without convergence, the calculation proceeds after printing a warning that the blade mode shapes did not converge.

Helicopter Trim

By the use of partial derivatives and a Newton-Raphson iteration new values of lateral and longitudinal cyclic pitch, main and tail rotor collective pitch, and body roll attitude are obtained and the Y force, Z force, and the moments about the X, Y, and Z axis are zeroed out. No attempt is made to zero the X force because of its nonlinear characteristics. However, some control of this force is provided by the provision for loading in the angle between the rotor shaft and the relative wind. This angle remains essentially unchanged during

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DISCUSSION (cont'd)

successive iterations. The sequence of events is as follows: The rotor blade motions are brought into steady state for initial values of cyclic and collective pitch. The rotor forces and moments and blade flapping are calculated, also the body forces and moments are calculated. The rotor Z force and helicopter gross weight are summed and compared with zero. If this in addition to blade flapping is also zero within the tolerances specified by the user, the tail rotor collective pitch and body roll attitude are calculated to zero the yawing moment and the side force. The calculation then proceeds to a new case or the transient section. If the rotor Z force does not balance the gross weight or the flapping is not zero and the maximum number of trim iterations has not been exceeded, the cyclic and collective pitches are adjusted and the rotor is brought to the steady state associated with the new control positions. This procedure continues until trim convergence is obtained or the maximum number of iterations is exceeded. If the case does not converge, after printing an appropriate warning, the calculation proceeds as in the converged situation.

Newton's method is used to predict new control positions at the end of each iteration. This method uses the nine partial derivatives associated with rotor Z force and flapping with respect to cyclic and collective pitch. The procedure is described in detail in the technical manual. The partial derivatives can be calculated internally by the program, either by parametric permutations or by linear theory. If known, provision has been made for loading them in via cards. This, if possible, will significantly reduce the compute time.

Transient Mode

The last section is the transient calculation and gust response. After helicopter trim has been attained the helicopter may be subjective to a vertical gust with a gust front of any arbitrary shape. Penetration of both the body and the rotor disc may be simulated. During the transient mode the response of each blade is calculated individually and the reference blade may be assumed at any azimuth position at the time the gust front and the rotor disc first come into contact. The gust can penetrate the disc at any angle and at any velocity. The gust front velocity is independent of the helicopter forward velocity. The actual velocity of gust penetration is calculated internally. At each azimuth position up to a maximum, specified by the user, blade stresses, deflections, and body motions are printed out. When the maximum azimuth angle (number of revolutions) is attained the program either terminates or proceeds to a new case as requested by the user.

DISCUSSION (cont'd)

Summary of What the Program Does and How It Does It

A simple flow chart may be used to demonstrate the five basic sections.
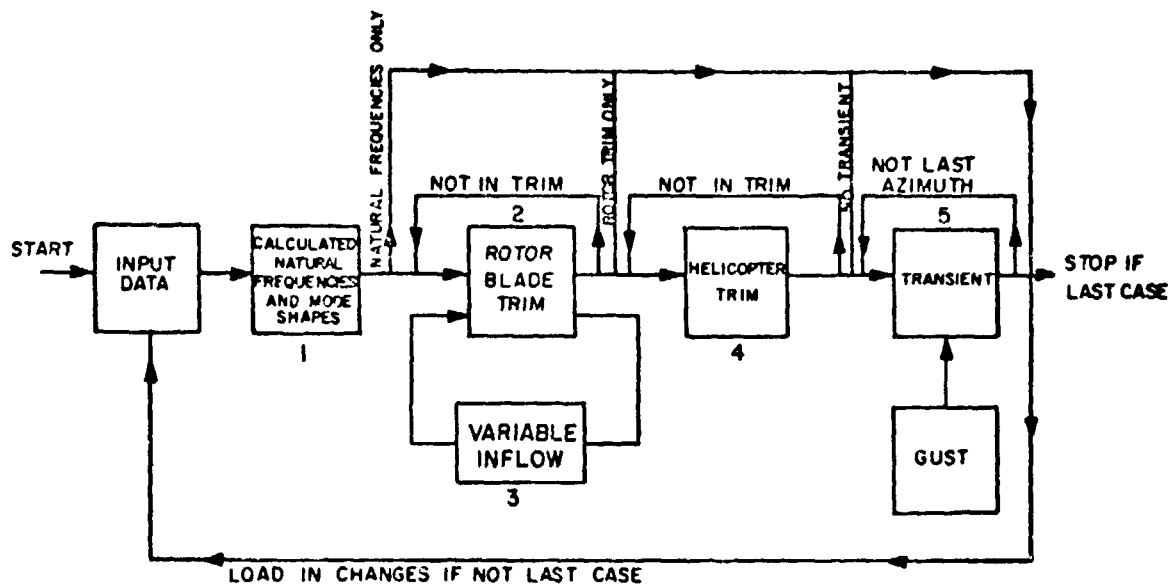
There are two basic modes of program operation. The first is the same as
Deck Y141 which calculates the aeroelastic response of a helicopter rotor
and support structure in a wind tunnel. This method of operation is described
in Reference d. The second is the inclusion of variable induced velocity.
The equations for the calculation of variable induced velocity and a detailed
description of the computer program may be found in Appendix C. The variable
induced velocity is completely coupled and no additional input cards are
required. The procedure is as follows. The procedure is divided into three
steps. Step 1 first calculates the coupled natural frequencies and mode
shapes if not loaded via card input then calculates rotor and/or helicopter
steady state utilizing the coupled blade dynamic equations as given in Refer-
ence c. Data files of basic input data and output from this case are written
for use in steps 2 and 3. Step 2 calculates the actual inflow across the
rotor disc utilizing the data files written during step 1. The equations
used are given in the references of Appendix C. When the induced velocities
have been calculated, they are written on a data file to be read by the
following step. Step 3 reloads the basic blade/helicopter data that was
written during step 1 and reads the variable induced velocities that were
written at the end of step 2. The coupled mode rotor blade response is then
calculated and the rotor/helicopter retrimmed again using the coupled mode

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dynamic equations as in Step 1. No further data need be loaded except "JCL" and control cards. Provision for modifying the data between steps has been provided by two individual calls to loader for each step. These options are normally used for debugging and the program could be modified to eliminate these double calls if desired. There is no need for the two calls to loader in step 1, but the second call was not bypassed to be consistent.

What the User Must Do

The user has four basic functions to perform.

1. Set up proper system control cards.
2. Load in all data in the proper format.
3. Be sure that what is asked for is really what is wanted.
4. Be able to recognize errors if they occur and make the appropriate corrections.

SECTION 1   BASIC DECK SET UP

1. Run card
2. JCL for step 1
3. Input data for step 1.
4. -1 99 -1.
5. Additional input data
6. -1 99 -1.
7. Curve Data (If card option used)
8. Mode Shapes (If loaded via cards)
9. JCL for step 2.
10. Control Card
11. -1 99 -1.
12. Changes to Basic Data Generated by step 1 if desired
13. -1 99 -1.
14. JCL for step 3
15. -1 99 2.
16. Changes to input data read in step 1
17. -1 99 -1.
18. Curve data (if loaded via cards)
19. JCL for termination

SECTION 2   DETAIL DESCRIPTION OF DECK SETUP

1. RUN CARD

Defined by system used.

2. JCL FOR STEP 1.

The JCL for all three steps and termination may be found in Appendix A.
Slight differences between systems may exist.

3. INPUT DATA FOR STEP 1

Card input data for the case being run in loader format. Much of the input
data may be loaded in shotgun form. (Unlike the curve data which is loaded
in block form no firm order to input need be adhered to.) The input para-
meters that are likely to change between cases are of this nature. Each
item is assigned a location number and may be loaded singularly if desired.
The location-parameter allocation is supplied in Sections 3 and 4. A
detailed description of the items is supplied in Section 5. The loader
format is as follows:
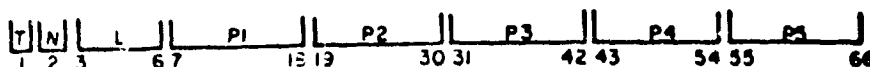
T	— to end case		

N   number of parameters to be loaded in on a card. Maximum of
         five.

L   Location of P1. P2 is loaded into L+1. P3 intl L+2, etc.
         Right adjusted.

P1   Numerical value of P1 anywhere between columns 7 and 18.

P2   Numerical value of P2 anywhere between columns 19 and 30.

P3, P4, P5, etc. is right adjusted and has no decimal point.

P1 - P5 must have decimal points.

N   May be any number from 1 to 5.

If L is not specified, P1 is assumed to follow the last location specified
by the previous card.

A sample of the shotgun input data appears in the Appendix.

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SECTION 2   DETAIL DESCRIPTION OF DECK SETUP (cont'd)

4. FIRST END OF DATA CARD

-1 99 ± 1. In loader format indicates end of data - begin calculation. If location 522 contains a 0., induced velocities are not to be calculated. -1. indicates subsequent cases to follow. a-1. indicates termination after current case has been completed. If location 522 contains a +1. data files are to be written for step 2.

5. ADDITIONAL DATA

This is only included for consistency with the rest of the setup. There would normally not be any cards loaded.

6. SECOND END OF DATA CARD

Same comment as Item 4.

7. CURVE DATA

Curve data loaded in CLOAD format or from data file 22. If location 135 contains A + 1. data file 22 is used. This must be preloaded with the section data. If location 135 contains A -1. data is loaded via cards.

A significant amount of input is not normally changed between cases during a specific computer run. The blade aerodynamic section data and the body aerodynamic data are good examples. The following is a complete list of the curve data that may, depending on requested options, be needed. These data are loaded by means of subroutine "CLOAD".

The following symbols are used,

α_R Local blade section aerodynamic angle of attack - degrees

M   Local blade section Mach No.

A   Function of $\dot{\alpha}_R$ (see Reference a)

B   Function of $\ddot{\alpha}_R$ (see Reference a)

α_F Body pitch angle of attack positive nose up - degrees

α_F Body yaw angle of attack positive clockwise - degrees

α_W Wing angle of attack positive pitch up - degrees

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SECTION 2   DETAIL DESCRIPTION OF DECK SETUP (cont'd)

CURVE ID	DESIGNATION	OUTPUT VARIABLE	UNIVARIANT	BIVARIANT	TRIVARIANT
		Load if Spar Data is Requested			
CLSP		CL	α_R		
CDSP		CD	α_R		
CMSP		CM	α_R		
		Load if Steady Two Dimensional or Unsteady Section Data is Requested			
CLDAT		CL	α_R	M	
CLDDAT		CD	α_R	M	
CMDAT		CM	α_R	M	
		Additional Data if Unsteady Section Data Option is Requested			
CNUNST		CN	α_R	A	B
CMUNST		CM	α_R	A	B
ASTCN		CL at stall	M		
ASTCM		CM at stall	M		
RCNM	CN_{ST} at Mach/CN_{ST} at Mach $= 0$		M		
CNREG1	Lower Boundary α_R of CN Transition Region		M		
CNREG2	Upper Boundary α_R of CN Transition Region		M		
CMREG1	Lower Boundary α_R of CM Transition Region		M		
CMREG2	Upper Boundary α_R of CM Transition Region;		M		

    (A full explanation of the mechanics of the unsteady aerodynamics option is presented in Reference f).

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SECTION 2   DETAIL DESCRIPTION OF DECK SETUP (cont'd)

Load if Body Force Option is Requested

CURVE ID	VARIABLE	UNIVARIANT
ENORM	Body normal force coefficient	α_F
BLONG	Body longitudinal force coefficient	α_F
BSIDE	Body side force coefficient	β_B
BPIT	Body pitching moment coefficient	α_F
BYAW	Body yawing moment coefficient	β_F
QTAIL	Tail dynamic pressure ratio	α_F
DWTAIL	Tail downwash	Generalized nondimensional main rotor slipstream penetration distance
NFHT	Normal force coefficient horizontal tail	Horizontal tail angle of attack degrees positive pitch up
NFVT	Normal force coefficient vertical tail	Vertical tail angle of attack degrees positive yaw clockwise

Load if Wing Option is Selected

WNGNF	Coefficient of wing normal force	α_W
WNGCF	Coefficient of wing chordwise force	α_W
WNGPM	Coefficient of wing pitching moment	α_W
WNGROL	Coefficient of wing rolling moment	α_W

Load if Gust Option is Selected

GUST	Value of vertical gust velocity in ft/sec	distance of gust penetration

SECTION 2   <u>Detail Description of Deck Set Up</u> (cont'd)

The following three curves have been added to facilitate
the use of the coupled variable induced velocity option. They need not
be loaded if induced velocities are not to be calculated.

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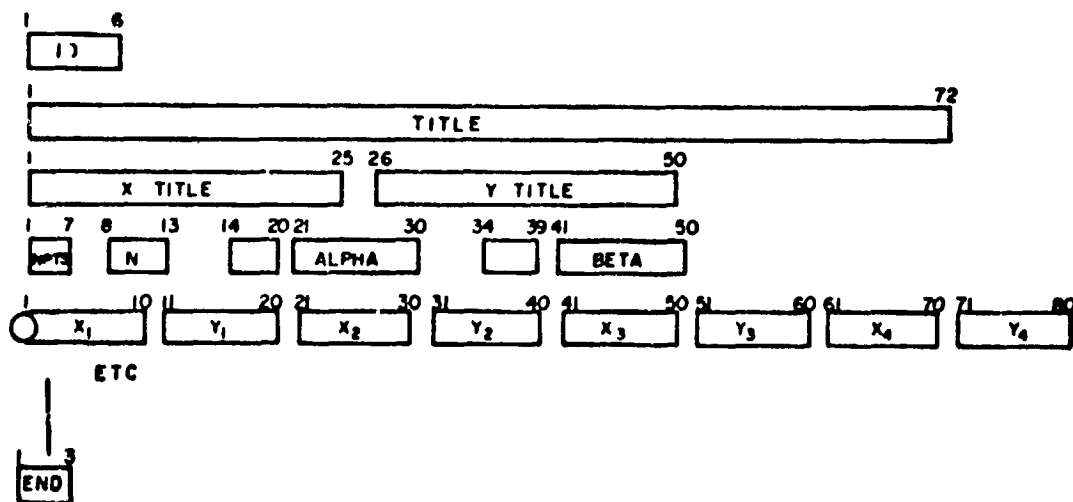SECTION 2   DETAIL DESCRIPTION OF DECK SETUP (cont'd)

Load if Variable Induced Option is Used

ACLZ   ALPHA for Zero C_L vs Mach No.

ACLM   ALPHA at Maximum C_L vs Mach No.

ASLP   Lift Curve Slope CL/RAD vs Mach No.

END

While a specific order of the curves is not necessary for operation of the program, a logical order, such as that given above, is desirable for good organization. Curves pertaining to options not requested need not be loaded. Curves loaded but not referenced do not interfere with program operations.

CLOAD Format

Curve data is input using subroutine CLOAD. This load curves in a standard, easily handled format, which is defined as follows:

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SECTION 2   DETAIL DESCRIPTION OF DECK SETUP (cont'd)

1. Alphanumeric entries are indicated by A.

2. Decimal entries are indicated by F must have decimal point.

Entry	Type	Card Number	Column Number	Comment
ID	A	1	1-6	Curve identification
TITLE	A	2	1-72	Title of curve as defined in data statement of calling program
X TITLE	A	3	1-24	X axis title
Y TITLE	A	3	25-48	Y axis title
NPTS	A	4	1-4	Coded literally, NPTS actually punched in columns 1-4
N	F	4	8-10	Number of X-Y pairs corresponding to one bivariant value
ALPHA	A	4	14-19	Bivariant title
ALPHA	F	4	21-30	Bivariant value
BETA	A	4	34-39	Trivariant title
BETA	F	4	41-50	Trivariant value
X,Y etc. etc.	F	5	1-10,11-20 etc. thru 80	X-Y pairs (N of them)

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END		last card	1-3	Coded literally, actually punch END in columns 1-3. Only if this is last curve.

After the X-Y pairs have been entered, cards 4 and 5 are continued for all parameter changes, bivariant varying fastest. If there is another curve, write curve identification and continue. 'END' is coded only when all curves are entered.

A sample list out of lift coefficient in univariant, bivariant and trivariant from is displayed in   Appendix A.

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SECTION 2   <u>DETAIL DESCRIPTION OF DECK SETUP</u> (cont'd)

8.   <u>MODE SHAPES</u>

If location 101 contains a -1. mode shapes are loaded via cards previously punched from the mode shape module. If location 101 contains a +1. mode shapes are calculated.

9.   <u>JCL FOR STEP 2.</u>

See Appendix A for details.

10.   <u>CONTROL CARD FOR INDUCED VELOCITY</u>

Normally no cards loaded. See Appendix C for detailed information.

11.   <u>END OF DATA</u>

-1 99 -1. is loaded.

12.   <u>CHANGES TO DATA LOADED FROM STEP 1.</u>

Normally no cards loaded. Can be used for debugging options. See Appendix C.

13.   <u>END OF DATA</u>

Load -1 99 -1.

14.   <u>JCL FOR STEP 3.</u>

See Appendix A for sample JCL.

15.   <u>STEP 3. CONTROL CARD</u>

To execute step 3 the following card must be loaded -1 99 2. (Loader Format).

16.   <u>CHANGES TO INPUT LOADED IN STEP 1.</u>

Normally no cards loaded. Can be used for debugging options.

17.   <u>END OF DATA</u>

Load -1 99 .. (Loader Format).

18.   <u>CURVE DATA</u> (If loaded via cards)

Same comment as Item 7.

SECTION 2   DETAIL DESCRIPTION OF DECK SETUP (cont'd)

19. JCL FOR TERMINATION

See Appendix A.

Mode Shapes for Step 3.

Unlike the curve data which must be reloaded, the mode shapes have been
written on a data file during step 1. and need not be loaded.

SECTION 3

A list of shotgun input items in ascending numerical order follows. This
list is most useful in setting up original (first time) runs or for deter-
mining what a particular item is from its location number.

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LOADER LOCATION	INPUT ITEM	UNITS
1	OMEGA-R (TIP SPEED)	FT/SEC
2	RADIUS	FT
3	OFFSET RATIO	ND/RADIUS
4	YOUNG'S MODULUS	PSI
5(15)	SEGMENT LENGTH	ND/RADIUS
20(15)	SEGMENT MASS (INCLUDING COUNTERWEIGHT)	SLUGS
35(15)	FLATWISE INERTIA	IN**4
50(15)	CHORDWISE INERTIA	IN**4
65(15)	TORSIONAL INERTIA	LBS-SEC**2
80(15)	TORSIONAL STIFFNESS (GJ)	LBS-INS**2
95	NUMBER OF BLADE MODES USED	
96	NOT USED	
97	NOT USED	
98	DEBUGGING OPTION DYNAMICS	
99	=-1. TO TERMINATE JOB	
100	TORSIONAL ROOT SPRING	IN-LBS
101	=+1.CALC MODES,-1.READ MODES	
102	NON ZERO TO PUNCH MODES	
103	=1. TO CALCULATE MODE SHAPES ONLY	
104	FLATWISE =0.,ARTIC =1.,NONARTIC	
105	NOT USED	
106-124	NOT USED	
125	EDGEWISE =0.,ARTIC =1.,NONARTIC	
126	PRINT HELICOPTER FORCES IF +1.	
127-128	NOT PART OF LOADER VECTOR	
129	MAXIMUM TRANSIENT AZIMUTHAL ANGLE	DEGS
130	NUMBER OF BLADES	
131	TIP LOSS	
132	INCREMENTAL DRAG COEFFICIENT	
133	=1.FOR NO AERODYNAMICS ON SEGMENT ONE	
134	NUMBER OF SEGMENTS (MUST BE 15.)	
135	-1. DATA ON CARDS +1. DATA ON FILE	
136	LINEAR TWIST IN AERODYNAMIC MODULE	DEGS
137	GRAVITY	FT/SEC**2
138	PRE-CONING	DEGS
139	PRE-LAGGING	DEGS
140	TAN(DELTA3)	
141	TAN(ALPHA1)	
142	NOT USED	
143	LAG DAMPER	LBS-SEC-FT/SEC
144	CHORDWISE STRUCTURAL DAMPING	ND
145	NOT PART OF LOADER VECTOR	
146	=1.TO PRINT ROTOR STEADY STATE TIME HISTORY	
147	TOTAL NONLINEAR TWIST IN AERODYNAMIC MODULE	DEGS
148	NOT PART OF LOADER VECTOR	
149	=1.TO RUN HELICOPTER TRANSIENT	

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150(15)	CHORD	FEET
165(15)	NONLINEAR TWIST IN AERODYNAMIC MODULE	DEGS
180(15)	I/C FLATWISE	IN**3
195(15)	I/C CHORDWISE	IN**3
210(15)	NOT USED	
225(15)	BUILT IN TWIST USED IN NATURAL FREQUENCY CALC.	DEGREES
240(15)	DIST QUARTERCHORD IS FORWARD OF ELASTIC AXIS	ND/RADIUS
255(30)	NOT USED	
285(15)	COUNTERWEIGHT MASS	SLUGS
300(15)	NOT USED	
315(15)	DIST CNTRWT IS FORWARD OF ELASTIC AXIS	ND/RADIUS
330(15)	BUILT IN TWIST FIRST DERIV	RAD/N.D.SPAN
345(15)	BUILT IN TWIST SECOND DERIV	RAD/N.D.SPAN**2
360(15)	DIST SPAR CENTROID FORWARD OF ELASTIC AXIS	ND/RADIUS
375(60)	NOT USED	
435(15)	DIST BLADE CG IS FORWARD OF ELASTIC AXIS	ND/RADIUS
450(15)	NOT USED	
465	AIR DENSITY	SLUGS/FT**3
466	SPEED OF SOUND	FT/SEC
467	SHAPE TOLERANCE	ND
468	NUMBER OF SHAPE TRIALS	
469-498	NOT PART OF LOADER VECTOR	
499	WARNING READ DESCRIPTION- NO. OF HELICOPTER TRIM ITERATIONS	
500-506	NOT PART OF LOADER VECTOR	
507	ALPHA,ANGLE MADE BY SHAFT WITH RELATIVE WIND	DEGS
508	NOT PART OF LOADER VECTOR	
509	TOLERANCE ON Z FORCE	LBS
510	TOLERANCE ON A1S FLAPPING	DEG
511	TOLERANCE ON B1S FLAPPING	DEG
512	NOT PART OF LOADER VECTOR	
513	A1S	DEGS
514	B1S	DEGS
515	THETA 75	DEGS
516	INFLOW RATIO, LAMBDA	ND/OMEGAR
517	HELICOPTER FORWARD VELOCITY	KNOTS
518	AZIMUTH INTERVAL (DYNAMICS)	DEGS
519	AZIMUTH INTERVAL (PRINT AND INTEGRATE)	DEGS
520	=1.FOR NONSYMMETRICAL AIRFOIL	
521	NOT PART OF LOADER VECOTR	
522	=1.TO USE COUPLED VARIABLE INDUCED VELOCITIES	
523	=1.TO PRINT COMPLETE TRANSIENT OF ROTOR	
524	NOT USED	
525	=1.TO PRINT NAT FREQUENCIES AND MODES DEBUG	
526	=1.TO PRINT AERODYNAMICS DEBUG	
527-532	NOT PART OF LOADER VECTOR	
533	TRANSIENT PRINT CONTROL. SEE TEXT	
534	CURVE NUMBER USED BY SEGMENT 1	
535	CURVE NUMBER USED BY SEGMENT 2	
536	CURVE NUMBER USED BY SEGMENT 3	
537	CURVE NUMBER USED BY SEGMENT 4	

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538	CURVE NUMBER USED BY SEGMENT 5	
539	CURVE NUMBER USED BY SEGMENT 6	
540	CURVE NUMBER USED BY SEGMENT 7	
541	CURVE NUMBER USED BY SEGMENT 8	
542	CURVE NUMBER USED BY SEGMENT 9	
543	CURVE NUMBER USED BY SEGMENT 10	
544	CURVE NUMBER USED BY SEGMENT 11	
545	CURVE NUMBER USED BY SEGMENT 12	
546	CURVE NUMBER USED BY SEGMENT 13	
547	CURVE NUMBER USED BY SEGMENT 14	
548	CURVE NUMBER USED BY SEGMENT 15	
549	=1.TO CALCULATE BODY FORCES	
550	=1. COUPLE FUSELAGE MOTIONS TO ROTOR BLADE	
551-552	NOT PART OF LOADER VECTOR	
553	BUTTLINE MAIN ROTOR	INS
554	DOWNWASH FACTOR , FUSELAGE	ND
555	FUSELAGE STATION , CG	INS
556	WATERLINE , CG	INS
557	FUSELAGE STATION , BODY DATA REF.	INS
558	WATERLINE , BODY DATA REF.	INS
559	FUSELAGE STATION , HORIZ TAIL AERO CENTER	INS
560	WATERLINE , HORIZ TAIL AERO CENTER	INS
561	FUSELAGE STATION , MAIN ROTOR	INS
562	WATERLINE , MAIN ROTOR	INS
563	MAIN ROTOR LONGITUDINAL SHAFT TILT	DEGS
564	LATERAL DISPLACEMENT, TAIL C OF PRESSURE	FEET
565	HORIZONTAL TAIL AREA	FEET**2
566	HORIZONTAL TAIL INCIDENCE ANGLE	DEGS
567	VERTICAL TAIL AREA	FEET**2
568	FUSELAGE STATION , VERT TAIL AERO CENTER	INS
569	WATERLINE , VERT TAIL AERO CENTER	INS
570	WINGSPAN	FEET
571	FUSELAGE STATION , WING AERODYNAMIC CENTER	INS
572	WATERLINE , WING AERODYNAMIC CENTER	INS
573	WING AREA	FEET**2
574	WING INCIDENCE ANGLE	DEGS
575	ROLL DAMPING TERM , WING	ND
576	FUSELAGE STATION , TAIL ROTOR HUB	INS
577	WATERLINE , TAIL ROTOR HUB	INS
578	BUTTLINE , TAIL ROTOR HUB	INS
579	TAIL ROTOR CANT ANGLE	DEGS
580	NUMBER OF BLADES , TAIL ROTOR	
581	TAIL ROTOR CHORD	FEET
582	TAIL ROTOR RADIUS	FEET
583	TAIL ROTOR ANGULAR VELOCITY	RAD/SEC
584	NOT PART OF LOADER VECTOR	
585	TAN DEL3 TAIL ROTOR (NOT USED AT PRESENT)	ND
586	TIP LOSS , TAIL ROTOR	
587	TAIL ROTOR BLADE INERTIA	SLUG-FT**2

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588	DOWNWASH FACTOR , TAIL ROTOR	
589	AIRCRAFT GROSS WEIGHT	LBS
590	POLAR MOMENT OF INERTIA ABOUT X AXIS	SLUG-FT**2
591	POLAR MOMENT OF INERTIA ABOUT Y AXIS	SLUG-FT**2
592	POLAR MOMENT OF INERTIA ABOUT Z AXIS	SLUG FT**2
593	X-Z PRODUCT OF INERTIA	SLUG-FT**2
594	FRACTION OF GROSS WEIGHT CARRIED BY WING	
595	WING MEAN AERODYNAMIC CHORD	FEET
596	LATERAL SHAFT TILT	DEGS
597	MASS MOMENT , TAIL ROTOR BLADE	SLUG-FT
598-604	NOT USED	
605(10)	INITIAL VALUE QW	
615(10)	INITIAL VALUE QW*	
625-799	NOT USED	
800	=1.CALCULATE HARMONICS OF BLADE BENDING ANGLE	
801-812	NOT PART OF LOADER VECTOR	
813	PARTIAL OF Z FORCE WITH RESPECT TO A1S	
814	PARTIAL OF Z FORCE WITH RESPECT TO B1S	
815	PARTIAL OF Z FORCE WITH RESPECT TO TH75	
816-818	NOT PART OF LOADER VECTOR	
819	PARTIAL OF A1S FLAPPING WITH RSPCT A1S FEATHERING	
820	PARTIAL OF A1S FLAPPING WITH RSPCT B1S FEATHERING	
821	PARTIAL OF A1S FLAPPING WITH RSPCT TH75	
822-824	NOT PART OF LOADER VECTOR	
825	PARTIAL OF B1S FLAPPING WITH RSPCT A1S FEATHERING	
826	PARTIAL OF B1S FLAPPING WITH RSPCT B1S FEATHERING	
827	PARTIAL OF B1S FLAPPING WITH RSPCT TH75	
828-836	NOT PART OF LOADER VECTOR	
837	1. FOR GUST	
838	VELOCITY OF GUST FRONT	FT/SE
839	ANGLE MADE BY PERP WITH X DIRECTION	DEGS
840	AZIMUTH POSITION OF REF BLADE AT INCIDENCE	DEGS
841	AZ INCREMENT FOR PRINT OF AZIMUTHAL STRESS	DEGS
842	=1.TO PRINT AZ AERO INFO IN TRANSIENT	
843	=1.TO PRINT BLADE MOTIONS IN TRANSIENT	
844	VALUE OF LAG DAMPER OF REFERENCE BLADE DURING TRANSIENT	
845	TH75/NF	DEGS
846	TW1/NF	DEGS
847-850	NOT USED	
851	TOTAL NUMBER OF BODY FREEDOMS	
852	NOT USED	
853	NUMBER OF RETAINED MODES	
854	ROTOR HEAD TRANSLATIONAL MODE NO -X	
855	ROTOR HEAD TRANSLATIONAL MODE NO -Y	
856	ROTOR HEAD TRANSLATIONAL MODE NO -Z	
857	ROTOR HEAD ROTATIONAL MODE NO - ABOUT X	
858	ROTOR HEAD ROTATIONAL MODE NO - ABOUT Y	
859	ROTOR HEAD ROTATIONAL MODE NO - ABOUT Z	
860	STRUCTURAL DAMPING	

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861-869	NOT USED
870	1. TO INPUT M, K
	2. TO INPUT M, K, G
	3. TO INPUT MD, KD, G
871	0. TO INPUT STIFFNESS, K
	1. TO INPUT FLEXIBILITY
872	1. TO PRINT EIGENVECTORS AND VALUES
873	1. TO PRINT ALL MATRICES
874	1. TO PRINT BODY VELS, ACCS
875	1. TO PRINT MODES
876	1. TO PRINT BODY DISPLACEMENTS
900	1. TO USE FLEXIBLE BODY MODES

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Section 4

A list of shotgun input items grouped by function follows. This list is useful for making changes to existing complete deck setups, or if the program is used to calculate natural frequencies and mode shapes only.

INPUT PARAMETERS IN LOGICAL ORDER

NATURAL FREQUENCIES AND MODE SHAPES

LOCATION	INPUT ITEM	UNITS
1	TIP SPEED	FT/SEC
2	RADIUS	FT
3	OFFSET RATIO	ND/RADIUS
4	YOUNG'S MODULUS	PSI
5(15)	SEGMENT LENGTH	ND/RADIUS
20(15)	SEGMENT MASS (INCLUDING COUNTERWEIGHT)	SLUGS
35(15)	FLATWISE INERTIA	IN**4
50(15)	CHORDWISE INERTIA	IN**4
65(15)	TORSIONAL INERTIA	LBS-SEC**2
80(15)	TORSIONAL STIFFNESS	LBS-INS**2
95	BLADE MODES USED	
100	TORSIONAL ROOT SPRING	IN-LBS
102	=1. TO PUNCH MODES	
103	=1. TO CALCULATE MODE SHAPES ONLY	
104	FLATWISE =0. ,ARTIC =1., NONARTIC	
125	EDGEWISE =0., ARTIC =1., NONARTIC	
525	=1. TO PRINT NAT FREQUENCIES AND MODES DEBUG	
101	=-1. TO READ MODES =+1. TO CALCULATE MODES	

PROGRAM CONTROL OPTIONS

499	WARNING READ DESCRIPTION- NO. OF HELICOPTER TRIM ITERATIONS
800	=1. CALCULATE HARMONICS OF BLADE ROOT FLAPPING
135	=-1. CURVE DATA ON CARDS =+1. ON DATA FILE
549	=1. TO CALCULATE BODY FORCES
550	=1. COUPLE FUSELAGE MOTIONS TO ROTOR BLADE
594	FRACTION OF GROSS WEIGHT CARRIED BY WING
837	=1. FOR GUST
149	=1. TO RUN HELICOPTER TRANSIENT
99	=-1. TO TERMINATE JOB AND CONTROL STEP WHEN USING VARIABLE INDUCED VELOCITIES
522	=1. TO USE VARIABLE INDUCED VELOCITIES
101	=-1. TO READ MODES =+1. TO CALCULATE MODES
102	=1. TO PUNCH MODES
104	FLATWISE =0., ARTIC =1., NONARTIC
125	EDGEWISE =0., ARTIC =1., NONARTIC
103	=1. TO CALCULATE MODE SHAPES ONLY & +1. IN 525 ALSO

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PRINT OPTIONS

146	=1. TO PRINT ROTOR STEADY STATE TIME HISTORY	
519	AZIMUTH INTERVAL (PRINT AND INTEGRATE)	DEGS
523	=1. TO PRINT COMPLETE TRANSIENT OF ROTOR	
533	TRANSIENT PRINT CONTROL, SEE USER GUIDE	
841	AZ INCREMENT FOR PRINT OF AZIMUTHAL STRESS	DEGS
842	=1. TO PRINT AZ AERO INFO IN TRANSIENT	

BLADE PARAMETERS

134	NUMBER OF SEGMENTS (MUST BE 15)	
2	RADIUS	FT
3	OFFSET RATIO	ND/RADIUS
130	NUMBER OF BLADES	
5(15)	SEGMENT LENGTH	ND/RADIUS
20(15)	SEGMENT MASS (INCLUDING COUNTERWEIGHT)	SLUGS
150(15)	CHORD	FEET
136	LINEAR TWIST IN AERODYNAMIC MODULE	DEGS
162 5)	NONLINEAR TWIST IN AERODYNAMIC MODULE	DEGS
147	TOTAL NONLINEAR TWIST IN AERODYNAMIC MODULE	DEGS
138	PRE-CONING	DEGS
139	PRE-LAGGING	DEGS
143	LAG DAMPER	LBS-SEC-FT/RAD
844	VALUE OF LAG DAMPER OF REFERENCE BLADE DURING TRANSIENT	
144	CHORDWISE STRUCTURAL DAMPING	ND
140	TAN(DELTA3)	
141	TAN(ALPHA 1)	
180(15)	I/C FLATWISE	IN**3
195(15)	I/C CHORDWISE	IN**3
240(15)	DIST QUARTERCHORD IS FORWARD OF ELASTIC AXIS	ND/RADIUS
315(15)	DIST CNTRWT IS FORWARD OF ELASTIC AXIS	ND/RADIUS
330(15)	BUILT IN TWIST, FIRST DERIV.	RAD/ND SPAN
345(15)	BUILT IN TWIST, SEC. DERIV.	RAD/ND SPAN**2
360(15)	DIST SPAR CENTROID FORWARD OF ELASTIC AXIS	ND/RADIUS
435(15)	DIST BLADE CG IS FORWARD OF ELASTIC AXIS	ND/RADIUS
468	NUMBER OF SHAPE TRIALS	
467	SHAPE TOLERANCE	ND
518	AZIMUTH INTERVAL (DYNAMICS)	DEGS
519	AZIMUTH INTERVAL (PRINT AND INTEGRATE)	DEGS
605(10)	INITIAL VALUE QW	
615(10)	INITIAL VALUE QW*	

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AERODYNAMIC OPTIONS

131	TIP LOSS
133	=1. FOR NO AERODYNAMICS ON SEGMENT ONE
132	INCREMENTAL DRAG COEFFICIENT
520	=1. FOR NONSYMMETRICAL AIRFOIL
534	CURVE NUMBER USED BY SEGMENT 1
535	CURVE NUMBER USED BY SEGMENT 2
536	CURVE NUMBER USED BY SEGMENT 3
537	CURVE NUMBER USED BY SEGMENT 4
538	CURVE NUMBER USED BY SEGMENT 5
539	CURVE NUMBER USED BY SEGMENT 6
540	CURVE NUMBER USED BY SEGMENT 7
541	CURVE NUMBER USED BY SEGMENT 8
542	CURVE NUMBER USED BY SEGMENT 9
543	CURVE NUMBER USED BY SEGMENT 10
544	CURVE NUMBER USED BY SEGMENT 11
545	CURVE NUMBER USED BY SEGMENT 12
546	CURVE NUMBER USED BY SEGMENT 13
547	CURVE NUMBER USED BY SEGMENT 14
548	CURVE NUMBER USED BY SEGMENT 15

ROTOR AND FLIGHT CONDITIONS

1	TIP SPEED	FT/SEC
513	A1S	DEGS
514	B1S	DEGS
515	THETA 75	DEGS
507	ANGLE MADE BY SHAFT WITH RELATIVE WIND	DEGS
516	INFLOW RATIO	ND/OMEGAR
517	HELICOPTER FORWARD VELOCITY	KNOTS
466	SPEED OF SOUND	FT/SEC
465	AIR DENSITY	SLUGS/FT**3
137	GRAVITY	FT/SEC**2

FUSELAGE PARAMETERS

549	=1. TO CALCULATE BODY FORCES	
550	=1. COUPLE FUSELAGE MOTIONS TO ROTOR BLADE	
563	LONGITUDINAL SHAFT TILT, MAIN ROTOR	DEGS
596	LATERAL SHAFT TILT, MAIN ROTOR	DEGS
589	AIRCRAFT GROSS WEIGHT	LBS
590	POLAR MOMENT OF INERTIA ABOUT X AXIS	SLUG-FT**2
591	POLAR MOMENT OF INERTIA ABOUT Y AXIS	SLUG-FT**2
592	POLAR MOMENT OF INERTIA ABOUT Z AXIS	SLUG-FT**2
593	X-Z PRODUCT OF INERTIA	SLUG-FT**2
553	BUTTLINE MAIN ROTOR	INS
555	FUSELAGE STATION, CG	INS
556	WATERLINE , CG	INS
557	FUSELAGE STATION, BODY DATA REF.	INS
558	WATERLINE , BODY DATA REF.	INS
561	FUSELAGE STATION, MAIN ROTOR	INS
562	WATERLINE , MAIN ROTOR	INS
554	DOWNWASH FACTOR, FUSELAGE	ND
594	FRACTION OF GROSS WEIGHT CARRIED BY WING	
573	WING AREA	FEET**2
570	WINGSPAN	FEET
595	WING MEAN AERODYNAMIC CHORD	FEET
574	WING INCIDENCE ANGLE	DEGS
575	ROLL DAMPING TERM, WING	
571	FUSELAGE STATION , WING AERODYNAMIC CENTER	INS
572	WATERLINE , WING AERODYNAMIC CENTER	INS
565	HORIZONTAL TAIL AREA	FEET**2
566	HORIZONTAL TAIL INCIDENCE ANGLE	DEGS
564	LATERAL DISPLACEMENT, TAIL OF PRESSURE	FEET
559	FUSELAGE STATION, HORIZ TAIL AERO CENTER	INS
560	WATERLINE , HORIZ TAIL AERO CENTER	INS
567	VERTICAL TAIL AREA	FEET**2
568	FUSELAGE STATION, VERT TAIL AERO CENTER	INS
569	WATERLINE , VERT TAIL AERO CENTER	INS

576	FUSELAGE STATION, TAIL ROTOR HUB	INS
577	WATERLINE , TAIL ROTOR HUB	INS
578	BUTTLINE , TAIL ROTOR HUB	INS
580	NUMBER OF BLADES, TAIL ROTOR	
581	TAIL ROTOR CHORD	FEET
582	TAIL ROTOR RADIUS	FEET
583	TAIL ROTOR ANGULAR VELOCITY	RAD/SEC
586	TIP LOSS , TAIL ROTOR	
587	TAIL ROTOR BLADE INERTIA	SLUG-FT**2
597	MASS MOMENT, TAIL ROTOR BLADE	SLUG-FT
579	TAIL ROTOR CANT ANGLE	DEGS
588	DOWNWASH FACTOR, TAIL ROTOR	

HELICOPTER STEADY STATE

499	WARNING READ DESCRIPTION-NO. OF HELICOPTER TRIM ITERATIONS	
589	AIRCRAFT GROSS WEIGHT	LBS
511	TOLERANCE ON B1S FLAPPING	DEG
510	TOLERANCE ON A1S FLAPPING	DEG
509	TOLERANCE ON Z FORCE	LBS
819	PARTIAL OF a1S FLAPPING WITH RSPCT A1S FEATHERING	
820	PARTIAL OF a1S FLAPPING WITH RSPCT B1S FEATHERING	
821	PARTIAL OF a1S FLAPPING WITH RSPCT TH75	
825	PARTIAL OF b1S FLAPPING WITH RSPCT A1S FEATHERING	
826	PARTIAL OF b1S FLAPPING WITH RSPCT B1S FEATHERING	
827	PARTIAL OF b1S FLAPPING WITH RSPCT TH75	
813	DZ/DA1S	
814	DZ/DB1S	
815	DZ/DTH75	

GUST PARAMETERS

837	=1. FOR GUST	
838	VELOCITY OF GUST FRONT	FT/SEC
839	ANGLE MADE BY PERP WITH X DIRECTION	DEGS
840	AZIMUTH POSITION OF REF BLADE AT INCIDENCE	DEGS
129	MAXIMUM TRANSIENT AZIMUTHAL ANGLE	DEGS

DEBUG OPTIONS

525	=1. TO PRINT NAT FREQUENCIES AND MODES DEBUG
526	=1. TO PRINT AERODYNAMICS DEBUG
98	= TO PRINT ROTOR BLADE DYNAMICS DEBUGGING

2. TO PRINT A, S, and T MATRIXES SEE REFERENCE   AT EACH
DELTA PSI PLUS ABOVE ITEMS

3. PRINT COMPONENT PARTS MAKING UP ELEMENTS OF S, AND T.

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SECTION 5   SUMMARY OF PROGRAM CONTROL OPTIONS

The following description defines in general terms what must be done to run
the various options of the program.

Location 101 controls the manner in which the mode shapes are made available
to the program. A +1.0 indicates that mode shapes are to be calculated by the
program. A -1.0 indicates that mode shapes are to be loaded in via punched
cards. A 0.0 indicates that mode shapes previously loaded or calculated are
to be used. If this location is zero for the first case a default option of
+1.0 is used. This location is reset to zero after each case. Therefore,
whenever new mode shapes are to be used this location must be ±1.0. Mode
shapes and frequencies as punched by the program are in the proper form and
may be read in directly.

Rotor Blade Steady State

The limit on the number of rotor revolutions for the establishment of rotor
steady state is loaded into location 468. Locations 605-624 have been pro-
vided for the starting values of the modal amplitudes and first derivatives.
If these initial guesses are close to the actual steady state values the
amount of compute time will be reduced. If the values are unknown, zero should
be loaded.

Rotor Trim Iteration

The maximum number of trails that the program is allowed to converg on rotor
Z force and flapping is loaded into location 499. The procedure used is
described in the technical report, Reference a, and the data needed is de-
scribed in Section 4 of this manual. If a zero is loaded into this location
no iteration is performed.

Body Forces and Helicopter Trim Iteration

This also includes the wing and the tail assembly aerodynamic forces. This
option is exercised by loading a +1.0 into location 549. If this option is
requested body physical constants, see Section 4, and body aerodynamic data,
see Item 10. of Section 2, must also be loaded. The addition of the body
forces has no effect on the rotor iteration. But tail rotor collective and
body roll attitude are adjusted to balance yawing moment and side force.

If a +1.0 is loaded into location 550 the fuselage motions are couple to the
blade dynamics. This is normally done if body forces are calculated. The
loading of +1.0 into locations 549 and 550 switch the program from a rotor
simulation to a helicopter simulation.

Transient Running

If a transient response is to be calculated this may be done by loading a +1.0 into location 149. It is also necessary to load a maximum value of azimuthal angle into location 129. This angle is in degrees. One revolution is 360 degrees, two revolutions, 720, etc. This angle does not include any trim iterations.

Gust Response

Penetration of a vertical gust may be simulated by loading a +1.0 into location 837. Other necessary gust parameters are given in Section 4.

Section 6 - Detailed Description of Loader Input Items by Location Number

1. Tip Speed

Main rotor tip speed expressed in feet/sec.

2. Radius

Main rotor radius measured from center of rotation expressed in feet.

3. Offset Ratio

Distance flapping and lagging hinges are displaced from the center of rotation nondimensionalized by the radius.

4. Young's Modulus

Young's modulus expressed in lbs/in^2.

5. Segment Lengths (15)

For aerodynamic and elastic considerations the rotor blade is considered to be composed of fifteen segments defined from root to tip, each having constant physical and aerodynamic properties. Although these segments can be any length desired, it is good practice to make the segments shorter outboard since the aerodynamic forces become nonlinear and are of greater relative magnitude. It is also common practice to make the last (Segment 15) equal to 1. - tip loss; see location 131. The segment lengths are nondimensionalized by the radius. Thus, it is essential that the sum of the segment lengths plus the offset ratio equal 1.0 ± .0001.

20. Segment Mass (15)

The mass of each segment expressed in slugs. This includes the mass of the counterweights.

35. Flatwise Area Moment (15)

Flatwise area moment of inertia about the elastic axis of each segment expressed in inches^4.

50. Chordwise Area Moment (15)

Chordwise area moment of inertia about the elastic axis of each segment expressed in inches^4.

65. Torsional Inertia (15)

Torsional mass moment of inertia about the elastic axis of each segment expressed in (Slug-Ft^2)/ft. (Note this is also expressible as lb-Sec^2.)

80. Torsional Stiffness (15)

Torsional stiffness of each segment expressed in lbs-in^2.

95. Number of Blade Modes (Frequencies)

The desired number of blade modes (including rigid body, flap, and lag modes, when applicable). Modes are included in order of increasing frequency. Up to 7 modes may be included.

98. Debugging

Nonzero in this location activates a debugging printout of the equations of motion.

99. End of Case/Job

A minus word count indicates the end of a case. A minus entry indicates the end of the run after the completion of the last case. If location 522 contains a +1. (variable induced velocity option), this location should contain a +1. for Step 1, or a +2. for Step 3.

100. Torsional Root Spring

Value of torsional spring in inch-lbs between blade and rotor head. If rigidly attached 1.0 x 10^{20} is recommended. This value may be loaded in as 1.0E20 (E type format), provided it is right adjusted in the parameter field of a normal loader card.

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101. <u>Mode Shape Calculation Control</u>

0.0   Do not calculate or read mode shapes and frequencies.
+1.0   Calculate frequencies and mode shapes.
−1.0   Load mode shapes and frequencies from cards.

This location must contain +1., if location 103 contains +1. for each case.
This location is automatically set to zero after mode shapes have been
calculated or loaded except when location 103 has a +1. to stop calculation
after obtaining modes. Thus the second and subsequent cases will use the
mode shapes and frequencies used by the first case. If at any time new
mode shapes are desired, this may be accomplished by loading at +1.0 into
this location. Again upon completion of the case, this control will be
reset to zero.

102. <u>Punch Modes</u>

A +1.0 in this location activates a routine that punches the mode shapes
and derivatives in a format compatible with this program.

103. <u>Mode Shape Only Option</u>

A +1.0 in this location indicates that the program is to stop after the
calculation of frequencies and mode shapes. In this case locations 101 and 525
must also contain a +1. for each case.

104. <u>Flatwise Rotor Hinge Condition</u>

Load 0.0 for articulated, +1.0 for nonarticulated.

125. <u>Chordwise Hinge Condition</u>

0.0 articulated chordwise +1.0 nonarticulated chordwise.

126.   <u>Debugging of Equations of Helicopter Motion</u>

A +1. in this location prints all forces acting on helicopter. Normally activated.

127-128

Not part of loader vector.

129.   <u>Maximum Transient Azimuth Angle</u>

The maximum value azimuth angle, PSI, may attain while in transient mode. For example, for two revolutions read in 720.

130.   <u>Number of Blades Main Rotor</u>

Limited to six if transient option is exercised. Any number may be used if transient not required.

131.   <u>Tip Loss, B</u>

Tip loss defines the length of the blade effective in producing lift. Normally tip loss is 0.97. However, in order to take into account all possibilities, provision is made for any tip loss. The CL and the CM of the last (Tip) segment are adjusted by the following formulas:

$$C_{L_{15}} = C_{L_{15}} \ (DX_{15} \ -1. \ + B)/DX_{15}$$

$$C_{M_{15}} = C_{M_{15}} \ (DX_{15} \ -1. \ + B)/DX_{15}$$

It may be seen from these formulas that if $DX_{15} = 1- B$; $C_{L_{15}}$ and

$C_{M_{15}}$ are zero. This condition will result in the best aerodynamic accuracy. Unfortunately, however, if B is closer to 1. than .98, this will result in a DX_{15} of .02 or less. This may result in some inaccuracy in the calculation of the natural frequencies and mode shapes. For this reason delta-x's less than .02 are not recommended. In this case, make $DX_{15} = $ .02 and let the program adjust CL and CM. Note DX_{15} must be greater than 1.-B. When using variable inflow tip loss is generally set to 1.0.

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132. Delta Drag

An incremental drag coefficient added to all aerodynamic drag coefficients obtained from the blade section properties. Empirically determined for a specific airfoil for the 0012   .002 is normally used.

133. Root Loss Option

A +1. loaded into this location omits all aerodynamic forces on the first (Root) segment.

134. Number of Segments

This is not an option. The program requires that 15. be loaded into this location.

136. Linear Twist

The total amount of built-in linear aerodynamic twist from center of rotation to blade tip expressed in degrees. Normally negative. If twist is nonlinear omit. If blade is not twisted, 0.0 must be loaded.

137. Gravity

Gravity expressed in ft/sec^2.

138. Preconing

Amount of preconing for nonarticulated rotors expressed in degrees. Positive up.

139. Prelagging

Amount of prelagging for nonarticulated rotors expressed in degrees. Positive in direction opposite to rotation.

140. Tangent of Delta-3

Tan of Delta-3. A positive value reduces the blade pitch as a linear function of blade root angle (flapping).

141. Tangent of Alpha 1

Tan of Alpha 1. A positive value increases pitch as blade lags.

143.   <u>Lag Damping</u>

Amount of lead/lag root end damping expressed in ft-lbs-sec/rad. This
does not affect chordwise frequencies in this analysis.

144.   <u>Chordwise Structural Damping</u>

Amount of chordwise structural damping of nondimensional form. Values
in the order of +0.02 to +0.04 are normally used. This does not affect
the chordwise frequencies.

145.

Not part of loader vector.

146.   <u>Print Time History</u>

A +1.0 loaded into this location results in a complete printout of the
steady state (or the last attempt to achieve steady state) blade modal
amplitudes and first and second derivatives.

148.

Not part of loader vector at present. Skip or load in zero.

149.   <u>Calculate Transient</u>

A +1.0 loaded into this location indicates that after helicopter trim has
been accomplished or the maximum number of iterations has been exhausted
a transient response considering each blade individually is desired.

150.   <u>Chord Main Rotor (15)</u>

The chord of each segment root to tip, expressed in feet.

165.   <u>Nonlinear Twist in Aerodynamic Module (15)</u>

If the twist is nonlinear the twist value of each segment is loaded in
root to tip expressed in degrees. This twist should be referenced to the
.75R radius station. The twist is used in the aerodynamic module. Twist
values for structural variations are loaded in locations 225 - 239.

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180.   **I/C Flatwise (15)**

The flatwise blade area moment of inertia divided by the distance from the elastic axis to the extreme flatwise structural fiber expressed in inches^3, loaded from root to tip. These values are used only to obtain stress from blade moments calculated by the program.

195.   **I/C Chordwise (15)**

The chordwise blade area moment of inertia divided by the distance from the elastic axis to the extreme chordwise structural fiber expressed in inches^3. Loaded for each segment root to tip. These values are used only to obtain stress from blade moments calculated by the program.

225.   **Built-In Twist -- Nonlinear**

The built-in twist values for each segment is loaded in root to tip and expressed in degrees. This twist should be referenced to the .75R radius station. These values are used in the natural frequency calculations. These values need not be loaded if they are the same as the aerodynamic nonlinear twist.

240.   **ETA C/4 (15)**

The chordwise distance from the quarter chord to the elastic axis, nondimensionalized by radius. Loaded for each segment root to tip. Positive for the quarter chord ahead of the elastic axis.

285.   **Counterweight Mass (15)**

Mass of the counterweight of each segment expressed in slugs, loaded root to tip..

300.   **Not used**

315.   **Counterweight Location (15)**

Chordwise distance from counterweight to elastic axis, nondimensionalized by radius loaded for each segment. Root to tip. Positive for each counterweight ahead of elastic axis.

330.   **Built-in Twist First Derivative (15), Nondimensional**

The first derivative with respect to radius distance (span) of the built-in twist. Local value of each station expressed as radians/nondimensional span. Loaded root to tip. Must be loaded if either aerodynamic or built in twist is nonlinear.

345. Built-in Twist Second Derivative (15)

Second derivative of built-in twist expressed as radians/nondimensional span squared. Loaded only if twist is nonlinear. Must be loaded if either built in or aerodynamic twist is nonlinear.

360. Location of Spar Centroid (15)

Chordwise distance from spar centroid to elastic axis, for each segment, nondimensionalized by radius. Loaded root to tip. Positive for spar centroid ahead of elastic axis.

375. Not used

390. Not used

405. Not used

420. Not used

435. Location of Blade C.G. (15)

Chordwise distance from blade center of gravity to elastic axis, nondimensionalized by radius. Positive for C.G. forward of elastic axis.

450. Not used

465. Air Density

Air density in slugs/ft^3.

466. Speed of Sound

Speed of sound in ft/sec.

467. Mode Shape Tolerance

Convergence tolerance on flapping, lea'ing, and modal amplitudes and first derivatives. Normally a value of 0.001 is used. A tolerance five times larger is automatically used when lead and lead prime are being tested for convergence.

468. Shape Trials

The number of rotor revolutions for mode shape convergence. If this number of rotor revolutions does not result in repeated values (within the specified tolerance) at azimuthal positions of 0.0 and 360, the calculation proceeds after printing a warning that the blade mode shapes did not converge.

469-498.

Not part of loader vector.

499.   Number of Trim Iterations

The maximum number of iteration trials allowed to converge on Z force
and a_{1s} and b_{1s} if articulated, or Z force and first harmonics of first
flatwise bending amplitude, if nonarticulated. If the parameters are not
trimmed within the specified tolerances after this number of attempts a
warning so stating is printed and the calculation continues.

If this number is positive the program calculates the partial derivatives
that are used in predicting new control positions. Since this requires
a substantial amount of computer time, these derivatives may be loaded
directly into the program. A negative number of trim iterations indicates
that the partials are to be loaded. If the number of trials is negative,
but all partials are zero, the partials are calculated by linear theory.
(See Reference a.)

If this option is used tail rotor parameters must be loaded. This does
not apply to the UNIVAC 1108/1110.

500-506.

Not part of loader vector.

507.   Angle Made by Shaft with Relative Wind

If the transient option or variable induced velocity is requested, it is
necessary to load in the inclination of the rotor shaft relative to the
direction of flight. This angle is positive for a shaft tilted aft.
This exercises some control on trim in the X direction. The units are
expressed in degrees. This should not be confused with the physical
shaft longitudinal tilt with respect to body (location 563).

508.

Not part of loader vector.

The comment not part of loader vector indicates that the particular
location(s) are not used for input in the particular program. Since
there are several versions of the normal modes program with inter-
changeable or nearly interchangeable inputs, it is not good practice
to modify any program and assign this location to a new input parameter.
This location can be skipped or loaded with zero with the rest of the
case information.

509-511.   Trim Tolerances

The following locations are used to input the convergence tolerances on rotor forces and moments.

509 Z force lbs
510 a_{1s} flapping deg.
511 b_{1s} flapping deg.

513.   AIS

Longitudinal cyclic pitch degrees, negative harmonic series, AlS cosine coefficient.

514.   BIS

Lateral cyclic pitch degrees, negative harmonic series, BIS sine coefficient

515.   Theta-75

Collective pitch at .75R degrees.

517.   Helicopter Forward Velocity, V

Forward velocity in knots.

518.   Delta-PSI Dynamics

Azimuthal integration interval in degrees used in the calculation of blade dynamics. Constraint 1: The value must be evenly divisible into 360. Constraint 2: (Only applicable if transient option is exercised). Value must be evenly divisible into the angular spacing of the blades.

Although there are no other physical restrictions on this parameter, particular care must be exercised in its selection since the computing time is inversely proportional to its size. Too large a value will result in a mathematical instability, while too small a value will result in long compute times. A handle on the optimum value may be found by dividing the highest blade frequency in cycles/rev (flatwise, chordwise, or torsional) into 36. The quotient obtained may then be rounded up to the nearest number that satisfies the defined constraints. In practice, this is often 5 deg. For 5-bladed rotors, this value would be 4 deg. It should be pointed out that if many modes are requested for stiff rotor blades, this parameter could be 1 deg. or less. This results in exceptionally long compute times. Normally a delta PSI less than 2 degrees indicates that too many modes have been requested.

519. Delta-PSI Force Integration

This Delta PSI is used in the calculation of the rotor forces in the printout. This Delta PSI must be selected such that (Delta PSI integrate)/ (Delta PSI dynamic) is an integer. Also the value must not be less than five degrees.

520. **Nonsymmetric Airfoil**

If this location is 0.0 the program will assume the airfoil is symmetrical and expect the blade section data to be defined only for positive angles of attack. If a +1.0 is loaded into this location the blade is assumed to be nonsymmetric and the program requires blade section data for both positive and negative angles of attack of the spar and steady data. The unsteady data is assumed symmetrical.
521. Not part of loader vector.

522. Coupled Variable Induced Velocities to be Calculated

A +1.0 in this location results in the writing of files to be used in the calculation of variable induced velocities. Note Alpha(s) (Location 507) must also be loaded. This is done in Step one. No further action is needed in Step three.

523. Print Full-Blade Time History

A +1.0 in this location prints a complete time history of blade modal amplitudes and derivatives at every azimuthal station, during both the trimming and transient modes. This results in a great deal of output and is primarily used for debugging.

524. Not used.

525. <u>Debugging of Natural Frequency and Mode Shapes</u>

A +1.0 in this location results in a printout of the iteration used to
determine natural frequencies. Also must be +1. if mode shape only option
is requested.

526. <u>Debug Aerodynamics</u>

A +1.0 in this location results in a printout of the components that make
up the aerodynamic forces and moments.

527 - 532.

Not part of loader vector.

533. <u>Print Azimuth Information</u>

·A -1.0 in this location will result in a printout of blade aeroelastic
and aerodynamic information at each azimuth position as defined by location
519, for both the trimming and the transient helicopter modes. A +1.0
suppresses the printout in the trimming mode. There are two further
controls available to reduce printout in the transient mode; see locations
841 and 842. A zero suppresses all azimuth printout.

534 - 548. <u>Section Data Option (15)</u>

In the calculation of C_L, C_D, and C_M there are three selections of airfoil
data tables (if tables are loaded) available for each segment. This is
controlled by the number indicated as follows:

+1.0 Use univariant data table f (angle of attack)
+2.0 Use bivariant data table f   (α, Mach number (M))
+3.0 Use unsteady data table f   (α, $\dot{\alpha}$, $\ddot{\alpha}$)
0.0 or not loaded defaults to +2.0 (bivariant data). Loaded for each
segment, any mixture is permitted. For loading in of airfoil data, see
Section 2.

549. <u>Calculate Body Forces</u>

A +1.0 in this location indicates that body forces are to be calculated.
For a helicopter gust study this must be used. If 0. is loaded body forces
are not calculated and body input items need not be loaded.

550. <u>Couple Rotor and Body</u>

A +1.0 in this location indicates that the rotor and the body are to be
coupled. For a helicopter gust study this should be used. Implementation
of this option feeds hub motions into the blade aerodynamics.

551 - 552.

Not part of loader vector.

553.   Buttline Main Rotor

Lateral distance from body plane of symmetry to location of center of rotor hub. Expressed in inches, positive to right.

554.   Fuselage Downwash Factor

Ratio of average downwash at fuselage to momentum value at rotor. (Nominal value 0.6).

555.   Fuselage Station C.G.

Fuselage station of body center of gravity expressed in inches.

556.   Waterline C.G.

Waterline of body center of gravity expressed in inches.

557.   Fuselage Station, Body Data Ref.

Fuselage station where body data are defined expressed in inches. Fuselage stations dimensions increase from nose to tail.

558.   Waterline, Body Data Ref.

Waterline where body data are defined expressed in inches. Waterline dimensions increase from bottom to top of aircraft.

559.   Fuselage Station of Horizontal Tail Center of Pressure

Expressed in inches.

560.   Waterline of Horizontal Tail Center of Pressure

Expressed in feet.

561.   Fuselage Station Center of Main Rotor Hub

Expressed in inches.

562.   Waterline Center of Main Rotor Hub

Expressed in inches.

563. <u>Main Rotor Shaft Tilt Relative to Body</u>

Expressed in degrees, positive forward

564. <u>Lateral Displacement Horizontal Tail Center of Pressure</u>

Expressed in feet, positive right.

565. <u>Horizontal Tail Area</u>

Square feet. For no horizontal tail use zero.

566. <u>Horizontal Tail Incidence Angle</u>

Expressed in degrees. Positive leading edge up.

567. <u>Vertical Tail Area</u>

Expressed in square feet. For no vertical tail use zero.

568. <u>Fuselage Station of Vertical Tail Center of Pressure</u>

Expressed in inches.

569. <u>Waterline of Vertical Tail Center of Pressure</u>

Expressed in inches.

570. <u>Wing Span</u>

Tip to tip expressed in feet.

571. <u>Fuselage Station of Wing Center of Pressure</u>

Expressed in inches.

572. <u>Waterline of Wing Center of Pressure</u>

Expressed in inches.

573. <u>Wing Area</u>

Square feet (total for both wings).

574. <u>Wing Incidence Angle</u>

Expressed in degrees. Positive leading edge up.

575. Wing Roll Damping Factor

Nondimensional roll damping contribution of the wing. It may be evaluated in terms of wing geometry using Figure 11 of NACA Report 1098, or, alternatively from DATCOM. Nominal value is -0.35.

576. Fuselage Station of Tail Rotor Hub

Expressed in inches.

577. Waterline of Tail Rotor Hub

Expressed in inches.

578. Buttline of Tail Rotor Hub

Expressed in inches. Positive to right.

579. Tail Rotor Cant Angle

Expressed in degrees. Positive tilt to right.

580. Number of Blades of Tail Rotor

Since linear theory is used for the tail rotor calculation, any number of blades may be used.

581. Chord of Tail Rotor

Chord is assumed constant, expressed in feet.

582. Radius of Tail Rotor

Expressed in feet.

583. Rotational Velocity Tail Rotor

Expressed in radians/sec.

584.

Not part of loader vector.

585.

Not part of loader vector.

586.   Tip Loss,Tail Rotor

Nominal value 0.97.

587.   Second Mass Moment of Inertia of Tail Rotor Blade

Expressed in slug-ft^2.

588.   Downwash Factor,Tail Rotor

Ratio of main rotor induced downwash at tail rotor to momentum downwash
at main rotor. A nominal value of 1.8 has been derived from wind tunnel
tests. Unless there are substantiating data for a particular application
the nominal value should be used.

589.   Aircraft Gross Weight

Expressed in lbs.

590.   Body IXX

polar moment of inertia of body about body roll axis, slug-ft^2.

591.   Body Iyy

Polar moment of inertia of body about body pitch axis, slug-ft^2.

592.   Body Izz

Polar moment of inertia of body about body yaw axis, slug-ft^2.

593.   Body Ixz

Product of inertia, slug-ft^2.

594.   Wing Option

Fraction of G.W. carried by wing.

595.   Wing Mean Aerodynamic Chord

Expressed in feet.

596.   Lateral Main Rotor Shaft Tilt

Expressed in degrees, positive tilt to left.

597.   First Moment of Inertia Tail Rotor Blade

Expressed in slug-feet.

598.

Not part of loader vector.

599.

Not part of loader vector.

600.

Not part of loader vector.

605 - 624   Initial Values of Mode Shapes and Derivatives

In order to reduce computer time, provision has been made to load in starting values of all mode shapes and their first derivatives in the event their steady or near steady state values are known. Values of derivatives are non-dimensionalized by omega.

631 - 782.

Not part of loader vector.

783.

Not used

800.   Harmonics of Flatwise Bending Angles

A +1.0 loaded into this location results in the calculation and printout of the harmonics of blade slope expressed in degrees at each blade station.

801 - 836.   Partial Derivatives

In the event location 499 contains a value less than zero, the trim iteration is performed using partial derivatives loaded in or previously calculated during prior case. Although provision has been made, for future expansion, to load in 36 derivatives, the present program only requires the following 9.

Loc 813 $\partial z/\partial A1S$	Loc 819 $\partial a1s/\partial A1S$	Loc 825 $\partial b1s/\partial A1S$
Loc 814 $\partial z/\partial B1S$	Loc 820 $\partial a1s/\partial B1S$	Loc 826 $\partial b1s/\partial B1S$
Loc 815 $\partial z/\partial \theta_{75MR}$	Loc 821 $\partial a1s/\partial \theta_{75MR}$	Loc 827 $\partial b1s/\partial \theta_{75MR}$

It is not possible to mix the modes, that is, load in some derivatives and have the remainder calculated internally. If the derivatives can be obtained by some means such as Bailey theory or derived from previous runs, this is highly desirable bacause of a substantial reduction in compute time. A word of caution, however, Derivatives obtained by linear theories have not proved reliable for high advance ratios or near stall conditions. This can result in divergent solutions. If the number of majcr iterations (Location 499) is negative and all the derivatives are loaded zero, the derivatives are automatically calculated by Bailey theory. Warning: if successive cases are run, the derivatives must be reset to zero if they are to be recalculated.

837.   Gust Option

A +1.0 in this location indicates that a gust penetration is to be impressed on the rotor after trim has been achieved.

838.   Velocity of Gust Front

Velocity of gust front in inertial axis system. This velocity is added to helicopter forward speed internally to obtain actual penetration velocity. See Figure 1.

839.   Gust Penetration Angle

Angle gust front makes with rotor disc at point of tangency. Expressed in degrees. See Figure 1. Page 51.

840.   Angle of Reference Blade

Azimuthal position of reference blade at time of gust tangency, expressed in degrees. See Figure 1.

841.   Azimuth Print Increment in Transient

Azimuth increment at which stress and deflection information is to be printed during transient mode. Note: contents of 841 divided by contents of 519 must be an integer.

842.   Aerodynamic Print Option

A zero loaded into this location will suppress the printing of blade aerodynamic information. This only applies during the helicopter transient mode.

843.   Print Transient Blade Motions Option

The printcut of blade modal amplitudes and derivatives is normally suppressed during the transient. A +1.0 will cause a complete printout of these quantities to occur.

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844.   Value of Lag Damper of Reference Blade During Transient

In order to investigate the effect of a defective lag damper, provision for
a different damping coefficient of the reference blade during a transient
has been provided. If this location is ignored or zero is loaded, the trim
value is assumed. If zero is desired, a small value such a .001 should be
loaded.

845.   Theta-75

Used in the calculation of coupled modes. Use only if different from aero-
dynamic theta-75.

846.   Linear Twist

Used in the calculation of coupled modes. Use only if different from aero-
dynamic linear twist.

Input Items Required when Rotor is Coupled to Flexible Support

The following inputs are required when it is desired to couple the rotor to
a grounded flexible support. Reference (d) describes the basis of the
theoretical model and defines the symbols used below.

851.   Number of Flexible Support Generalized Coordinates, N

Generalized coordinates selected by the user to describe the support are
typically linear and angular displacements of points on the support structure.
The number of such coordinates is N (N $\leq$ 69). It is necessary to load N to
define the order of the matrices describing the support structure.

852.   Not used

853.   Number of Modes, M

The number of support structure normal modes retained for the analysis is
M. In general the number of normal modes must be less than or equal to the
number of generalized coordinates (M $\leq$ N). If the user loads non-diagonal
mass and stiffness matrices, M will be number of support structure normal
modes calculated in the program, and subsequently used to reduce the support
equations to normal form. If the user loads diagonal mass, stiffness, and
modal matrices, M will designate the subset of the number of normal modes
selected from among the loaded modes that he desires to use.

854 - 856.   <u>Rotor Head Linear Displacement Numbers N_1^*, N_2^*, N_3^*</u>

Rotorhead linear displacements are u, v, and w (Ref. (g)). These displacements are members of the set of generalized coordinates for the support structure. Each generalized coordinate is designated with an integer number, these numbers ranging from one for the first generalized coordinate to N for the last generalized coordinate in the set. Integer numbers designating the generalized coordinates u, v, and w are N_1^*, N_2^*, and N_3^*. For example if there are N = 55 generalized coordinates and N_1^* = 20, N_2^* = 25, N_3^* = 51, then u, v, and w are the 20th, 25th and 51st generalized coordinates in the set of 55 coordinates.

857 - 859.   <u>Rotor Head Angular Displacement Numbers, N_1, N_2, N_3</u>

The preceding remarks under 854 - 856 apply here with N_1, N_2, and N_3 treated now as numbers defining the locations in the set of generalized coordinates of hub angular displacements θ_1, θ_2, and θ_3 (Ref. (d)).

860.   <u>Support Structure Damping Constant, g^*</u>

Structural damping of each normal mode of the support is represented by the same constant ratio g^* = 2 x c/c_{crit} where c is the actual damping of a mode and c_{CRIT} is the critical damping ratio of a mode. It is emphasized that g^* is <u>twice</u> the critical damping ratio c/c_{CRIT}.

870.   OP(1) = 1. - Input generalized mass and stiffness matrices [m] and [k]

OP(1) = 2. - Input same as for OP(1) except that modal matrix [γ] is added input.

OP(1) = 3. - Input normalized generalized mass and stiffness matrices [m^D] and [k^D] and γ. See remarks in the next section referring to [γ] input.

871.   OP(2) = 0. - Input stiffness matrix [k]
OP(2) = 1. - Input flexibility matrix $[k]^{-1}$

In the following, no printing (or action) occurs if switches are given values other than those indicated. (See Reference d)

872.   OP(3) = 1. - Prints eigenvalues (squares of natural frequencies) and modal columns.

873.   OP(4) = 1. - Prints matrices [m^D], [k^D], $[\gamma]^T$ [c] [γ].

874.   OP(5) = 1. - Prints rotor head linear and angular accelerations and velocities as a function of time (rotor azimuth).

875.   OP(6) = 1. - Prints modal accelerations, velocities, and amplitudes as a function of time (rotor azimuth).

876. OP(7) = 1. - Prints rotor head linear and angular displacements refer-
red to undisturbed shaft axes as function of time (rotor azimuth).

900. OP(8) = 1. - Flexible module switch links support module to main pro-
gram.

Input - Matrices

Matrix inputs are

[m]   N X N generalized mass matrix

[k]   N X N generalized stiffness matrix

[m^D] M X M diagonal mass matrix for normal coordinates

[K^D] M X M diagonal mass matrix for normal coordinates

[c]   N X N non-proportional damping matrix

[γ]   N X M modal matrix

The values assigned by the user to OP(1) and OP(2) determine which of these
matrices is input (see "Matrix Input Options"). Matrix inputs immediately
follow loader input. Each matrix input is preceded by a lead card containing
a key in column 64 designating the type of the matrix. Keys are

M   Mass matrix

K   Stiffness or flexibility matrix

C   Non-proportional damping matrix

G   Modal matrix

E   Termination key

A key is followed by non-zero elements of its matrix. Elements not input
are treated as zeroes. This feature facilitates the handling of sparse matrices,
like diagonal matrices. Null matrices require no key. Each element is pre-
ceded by integers defining its row and column subscripts respectively. Input
of row, column, and element value is formatted

3(I3,   I3,   E15.6

Row   Col.   Element

The '3' indicates that a maximum of three matrix elements may be placed on

each card. The last such non-zero element is followed by the key for the next matrix. This organization is repeated until all non-zero elements are input. E in column 64 terminates these data. Only non-zero elements on and above the leading diagonals of [m] and [k] need to be input. The subroutine assumes these matrices to be symmetric and forms lower elements accordingly. However, if the user wishes to supply the complete [m] and [k] matrices, he may do so without penalty. When OP(1) = 3 and [c] is identically zero, only the six rows for [γ] for the six rotor head displacements need to be input. The elements input are

$$\gamma_{ji} \qquad J = N_1^*, \ N_2^*, \ N_3^*, \ N_1, \ N_2, \ N_3$$

$$i = 1, \ 2 .. \ M$$

If OP(1) = 3 and [c] is not identically zero, all non-zero elements of the N X M matrix [γ] are input.

Display

All loader and matrix card inputs are displayed to enable the user to check his input. Optional displays are generated according to values assigned to switches on input. If the switches are not assigned the values indicated below, printing does not occur.

OP(3) = 1. - Eigenvalues (γ, squares of natural frequencies) in column format, followed by each eigenvalue accompanied by its eigenvector.

OP(4) = 1. - Diagonal stiffness and mass matrices for normal coordinates $[k^D]$ $[m^D]$. Non-proportional damping in normal coordinates [γ] [c] [γ].

OP(5) = 1. - Rotor head linear and angular accelerations and velocities at each instant of time (rotor azimuth), referred to inertial and shaft axes.

TAIL
AZIMUTH = 0.0
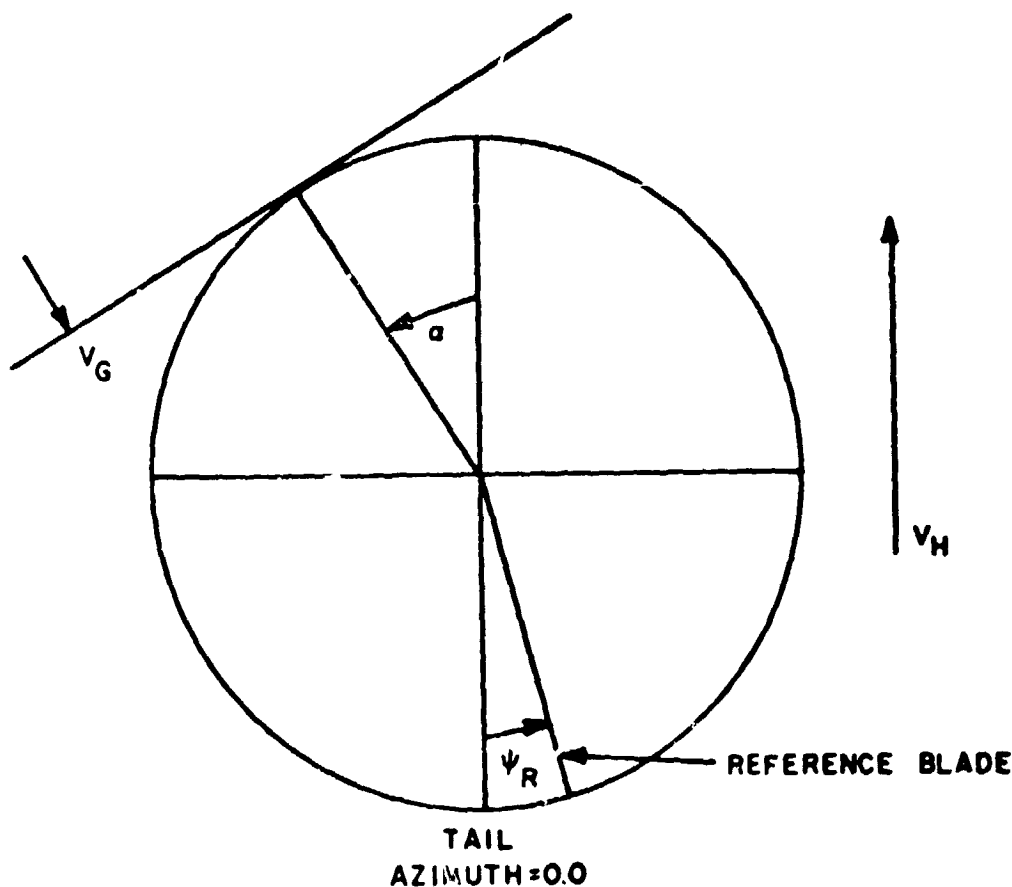
V_G,   Gust front velocity in feet per second.

V_H,   Helicopter velocity in knots.

α ,   Penetration angle in degrees.

ψ Angle of reference blade in degrees.

Summary of Loaded Input

There are three forms of input data; shotgun, block, and curve. The shotgun loader has the capability of loading only values that need to be changed between cases. This requires the assignment of a specific loader location for each of these items. These locations are given in numerical order in section three and in logical order in section four. The block loader is used for data such as normal modes and induced velocity where large blocks of data are loaded without the likelihood of individual numbers of a block changing between cases. The third type is curve data. These are in a form that involves a dependent variable as a function of one or more independent variables. The program uses these data to interpolate linearly between points such that the value of the dependent variable may be determined for any values of the independent variables with the defined range.

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Section 7. Common Errors and Pitfalls

The following errors and pitfalls have been found to occur most often in the
operation of this and similar programs. Check carefully before running.

1.   Improper setup of deck.

2.   Requesting incorrect options.

3.   Leaving out word count on loader card.

4.   Incorrect data location.

5.   Leaving out decimal point (when required). This will usually default
        the decimal point to the extreme right of the number field resulting in
        a ridiculously large value of the parameter loaded.

6.   Delta PSI dynamic too large. This results in a mathematical instability
        of the blade dynamic response. See write up of location 518.

7.   Incorrect values of the input parameters.

Section 8. Error Messages and Diagnostics

Alpha Greater Than 360

The most common error message generated by the program is "ALPHA greater
than 360". This is followed by the values of the local angle of attack in
degrees that is greater than 360, UP, UT, PHI, THK, TWIST, PSI, GTQT, and
N.

UP, Component of velocity of air parallel to shaft, non-dimensionalized by
    tip speed.

UT, Component of velocity of air perpendicular to shaft, non-dimensionalized
    by tip speed.

PHI, Inflow angle in degrees (ARCTAN $\frac{UP}{UT}$).

THK, Blade pitch excluding twist, in radians.

TWIST, Contribution of blade twist to angle of attack at specified station,
       in degrees.

PSI, Azimuthal position of difficulty, expressed in radians.

GTQT, Torsional deformation at station, expressed in radians.

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N, Blade station of difficulty. Station one is at root.

There is a multiplicity of causes of this error message. Examination of the diagonostic printout should indicate the probable cause. The following is a list of likely candidates.

    (a) Delta-PSI (location 518) too large.
    (b) Missing decimal point in input vector.
    (c) Improper input values.
    (d) Wrong location used in input vector.
    (e) Blade is truly dynamically unstable.

Word Count is Missing

This diagnostic can have only two causes. The word count is missing from a card in the data vector, or the input data are set up improperly as defined by the input options as requested. This could be either data out of place or data set up wrong.

Program Interrupt - Various Information

Although this diagnostic does not stop the calculation and can result in answers that may appear meaningful, under no conditions should it be ignored or the results believed. If the trouble cannot be found this author should be contacted.

Flapping Did Not Converge

This is a very common warning that indicates the blade mode shapes and first derivatives did not converge to within the user specified tolerance after the prescribed maximum number of revolutions. Examination of the values of the mode shapes and their first derivatives at the 360 degree azimuth position for the last and next to last revolution will reveal how serious the discrepancy is. The calculation will proceed after printing the warning.

Trim Iteration Failed to Converge

This warning indicates that either the Z force did not converge to the helicopter gross weight or the flapping did not trim to zero, within the specified tolerances. The final values obtained are printed for inspection. The calculation proceeds after printing the warning.

Error in Curve Data Lookup

In the event one of the independent parameters is out of range of the
section data "IERR=2" is printed along with the name of the curve. The
dependent variable is calculated using the max or min value of the parameter
out of range. Calculation continues.

In the event only one point is present on a curve the diagnostic "IERR=5"
is printed and the name of the curve. A listout of the data should be
checked.

In the event a curve is requested that is not present (or the curve name is
misspelled) the name in error is printed along with all legal names.

Section 9. General Suggestions for Running Program

1. Do not request unnecessary mode shapes, particularly when first
    starting out with a new blade. Two flatwise, one edgewise and
    one torsional is accurate enough for initial analysis. The use
    of a large number of mode shapes will require a small delta PSI
    (Location 518) and result in long compute times.

2. Keep Delta PSI (Location 518) as large as possible, so long as
    the blade dynamics do not go unstable.

3. When running in the transient mode, load in the partial deriva-
    tives whenever possible or use the linear derivative calculation
    option. This will reduce compute time.

4. Use the print suppress options. This will not only reduce the
    amount of useless numbers but will reduce compute time.

5. Always check and recheck the deck setup. This is the most
    common cause of error. If the program fails, and you are unable to
    determine what has gone wrong, obtain a complete listout of the
    input before seeking help.

Section 10. Accuracy

The accuracy of the analysis is best determined empirically. For any
particular helicopter and flight condition begin with a few modes and as
large delta PSI as feasible. The number of modes can then be increased
and the delta PSI reduced while noting the resultant change in the answers.
When the change is smaller than the allowable accuracy the proper values
have been established.

Section 11. Output Printout
Modal Amplitudes at Beginning of Revolution

This page of printout is designed to evaluate the convergence of the rotor to a steady state. It displays some data on the condition being analyzed, and the characteristics of the response at the beginning of each revolution.

Output headings are:

OMEGA-R	Rotor Tip Speed; ft/sec
RADIUS	Rotor Radius, ft
RHO	Density of Air, $lb\text{-}sec^2/ft^4$
SPEED OF SOUND	Speed of Sound, ft/sec
LINEAR TWIST	Rate of Twist, the Twist divided by non-dimension- alized radius, deg. ,Aerodynamic
A1S	Longitudinal cyclic pitch, deg.
B1S	Lateral cyclic pitch, deg.
THETA-75	Collective pitch at the 3/4-radius, deg. , Aerodynamic
LAMBDA	Inflow ratio
MU	Advance ratio, $V/\Omega R$, non-dimensional
VELOCITY	Aircraft forward speed, knot

The next two lines give the flapping and lead angles at the start of the revolution, deg.

REV	Number of revolutions of rotor
BETA	Blade root end angle for out of plane deflection, measured positive upward from precone angle, radians
BETA*	First derivative of BETA with respect to azimuth angle (non-dimensionalized time, time multiplied by rotor speed)

BETA**   Second derivative of BETA

DEL   Blade root end angle for inplane
                    deflection, measured positive for lead
                    forward from prelag angle, radians

DEL*   First derivative of DEL

DEL**   Second derivative of DEL

The next three lines give the amplitudes of the blade modes and their
derivatives. Modes are listed from left to right, in the order in which they
are tabulated on the previous printout page. The readings are:

QA   Modal amplitude, non-dimensionalized
                    by radius

QA*   First derivative of QA with respect to
                    azimuth angle (time non-dimensionalized
                    by rotor speed), ND

QA**   Second derivative of QA with respect to
                    azimuth angle, ND

A statement at the bottom of the page will inform the user if convergence
to a steady state is not achieved within input flapping tolerance limits.
In any event the calculation will proceed, defining the response for the
last revolution.

Model Amplitudes and Derivatives

This set of output pages gives the model amplitudes and radial derivatives
at requested azimuth angles for the last revolution. The headings are:

PSI   Azimuth angle, deg.

BETA   Blade out of plane root end angle, positive for
                    upward deflection, radians

LEAD   Blade inplane root end angle, positive for blade
                    leading, radians

Q1 to Q10   Amplitudes of blade modes 1 to 10. Zeros in
                    output indicate mode is not loaded in input

( )*   The symbols indicate first and second derivatives
( )**   with respect to azimuth angle (non-dimensionalized
                    time) of the above quantities.

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Blade Loading and Response

This set of output pages gives information on blade segment angle at attack, airflow, and response at each of a selected set of azimuthal locations for the last revolution. The data are grouped by azimuth angle which is given by the initial heading PSI = . The data are in columns which are tabulated from root to tip. The far left end right columns list the station number. The headings are:

BETA	Angle between blade segment elastic axis and plane perpendicular to shaft rotational axis, positive for deflections upward, deg.
VERT. DEF.	Out of plane deflection of center of blade segment referenced to blade root end, positive upward, ft.
LAG ANGLE	Angle between blade segment elastic axis and a vertical plane through blade root end, positive for lag aft, deg.
INPLANE DEF.	Inplane deflection of blade segment, positive aft, ft.
TORS. DEF.	Elastic twist of blade segment, positive for leading edge up, deg.
BR STRESS	The sum of the flatwise bending stress and edgewise bending stress, psi
FLAT STRESS	Flatwise bending stress relative to blade segment principal axis, defined by segment bending moment and input value for I/C, positive for center of curvature above blade, psi.
EDGE STRESS	Edgewise bending stress relative to blade segment principal axis, defined by segment bending moment and input value of I/C, positive for center of curvature ahead of blade, psi.
TORS. MOMENT	Blade segment torsional moment, positive nose up at outboard end, in-lb
GUST	Velocity of gust at center of blade segment, parallel to shaft axis, positive for airflow upward through rotor, fps or inflow velocity positive for upflow fps. Depending on option selected
XCEN	Distance from center of rotation (shaft axis) to center of blade segment, non-dimensionalized by rotor radius,

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VAR. LAMBDA	Velocity of gust at center of blade segment, parallel to shaft axis, positive for airflow upward through rotors, fps or inflow velocity positive for upflow, fps. Depending on option selected
PHI	Tan^{-1} (Up/Ut), the angle between the direction of airflow over the blade segment and a plane perpendicular to the shaft, positive for upflow through the rotor disc and flow from leading to trailing edge of blade, deg.
ALPHA	Aerodynamic angle of attack between airflow and blade chord line, deg.
MACH No.	Mach Number of airflow at blade segment, non-dimensional
CL	Lift coefficient of blade segment, non-dimensional
CD	Drag coefficient of blade segment, non-dimensional
CM	Pitching moment coefficient of blade segment, non-dimensional
FW. AERO. LOAD	Flatwise aerodynamic loading per spanwise distance relative to blade segment chord line, positive for lift on segment, lb/in
EW. AERO. LOAD	Edgewise aerodynamic loading per spanwise distance relative to blade segment chord line positive for load aft (drag) lb/in
TORS. AERO. MOM.	Torsional aerodynamic moment about blade segment quarter chord, positive nose up, in-lb/in

Summary of Blade Aeroelastic Behavior

The values of various items are displayed at the indicates radial stations measured from the center of rotation.

Centrifugal force in lbs

Total max and min flatwise deflection including rigid body in feet max and min

Total max and min edgewise deflection including rigid body in feet

Total max and min torsional deflection in degrees

Vibratory stresses in lbs/in^2

Average stresses in lbs/in^2

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Vibratory moments in inch-lbs (Assuming I/C's in inch^3)

Average moments in inch-lbs (Assuming I/C is in inch^3)

Force Integration

This is a summary of the total rotor system loading and flight condition characteristics, calculated on the basis that all blades of the rotor are acting the same at a given azimuth angle.

The first two lines are non-dimensional aerodynamic parameters based on aerodynamic blade loads only, defined as follows:

CZ   Z Force, $F_z/\pi\rho\Omega^2 R^4$

CQ   Torque Coefficient, $Q/\pi\rho\Omega^2 R^5$

CX   X Force, $F_x/\pi\rho\Omega^2 R^4$

CL   Lift, $L/\pi\rho\Omega^2 R^4$

CPM   Pitching Moment, $M_p/\pi\rho\Omega^2 R^5$

CRM   Rolling Moment, $M_R/\pi\rho\Omega^2 R^5$

CPF   Propulsive Force, $F_p/\pi\rho\Omega^2 R^4$

These are divided by solidity $\sigma = \dfrac{bc}{\pi R}$ to give coefficient-solidity ratios:

CZ/SIGMA $CZ/(bc/\pi R)$

CQ/SIGMA $CQ/(bc/\pi R)$

CX/SIGMA $CX/(bc/\pi R)$

CL/SIGMA $CL(bc/\pi R)$

CPM/SIGMA $CPM/(bc/\pi R)$

CPF/SIGMA $CPF/(bc/\pi R)$

The next two lines provide dimensional aerodynamic rotor force, moment, and power data. The headings are:

Z FORCE   Rotor force F_z along the shaft axis, positive downward, lb

X FORCE   Rotor force F_x in shaft axis system (in plane of rotor), positive forward, lb

TORQUE	Rotor torque required to drive rotor, ft-lb
ROLLING-MOM	Rolling moment generated by rotor in shaft axis system, positive for roll with right side down (right hand rule about forward axis) ft-lb
PITCH-MOM	Pitching moment generated by rotor, positive for pitch with nose up, ft-lb
ALPHA(S)	Rotor shaft angle relative to perpendicular to direction of flight. $\alpha_s = \tan^{-1}\left[\dfrac{\lambda}{\mu} - 2\mu\sqrt{\dfrac{C_x}{\mu^2 + \lambda^2}}\right]$ if constant inflow is used. α_s = input value if variable inflow is used.
Y FORCE	Side force F_y generated by rotor, positive for force to the right, lb
LIFT	Lift force L generated by rotor, perpendicular to direction of flight, positive upward, lb
PROPULSIVE FORCE	Propulsive force F_p generated by rotor along dirrection of flight, positive forward, lb $$F_p = F_z \sin\alpha_s + F_x \cos\alpha_s$$
HORSEPOWER	Power required to drive rotor, horsepower.
EQUIVALENT DRAG	The equivalent drag force, F_{ED} generated by the rotor along direction of flight, positive rearward, lbs $$F_{ED} = \frac{550 \ (\text{HORSEPOWER})}{V} - F_p \qquad \text{V in ft/sec}$$
EQUIVALENT L/D	Lift/drag ratio for the rotor, non-dimensional $$\text{EQUIVALENT L/D} = \frac{L}{F_{ED}}$$
EQUIVALENT PARASITE AREA	The equivalent drag surface area, A_{ED}, due to the rotor, as defined by $$A_{ED} = \frac{F_{ED}}{\frac{1}{2}\rho V^2}$$

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The last two lines of printout provide data on the controls, flight condition, and some blade properties. The headings are:

A1S — Longitudinal (cosine component) cyclic pitch, positive for maximum angle over nose of aircraft, deg.

B1S — Lateral (sine component) cyclic pitch, positive for maximum angle over left side of aircraft, deg.

TH75(MR) — Collective pitch, for main rotor, deg.

LAMBDA — Inflow ratio, non-dimensional

MU(MR) — Advance ratio, non-dimensional

TH75(TR) — Collective pitch on tail rotor, deg.

BODY ROLL ATTITUDE — Body roll attitude, positive right wing up. deg.

VELOCITY — Aircraft forward velocity, knot

BCQD/SIGMA

A measure of the blade drag moment at a given azimuth angle, PSI. The magnitude shown is the largest value on the retreating half of the rotor disc. Values of 0.004 and 0.008 are indicative of the lower and upper stall limits (the onset of stall and deep stall penetration respectively). This non-dimensional parameter is defind by

$$\frac{bC_{Q_D}}{\sigma} = \tfrac{1}{2} \int_0^{1'} C_d\, U_t\, U\, x\, dx$$

PSI — The blade azimuth angle at which the maximum value of

$$\frac{bC_{Q_D}}{\sigma}$$ occurs.

BLADE WEIGHT

Blade weight, lbs

FIRST MOM — Blade first mass moment about blade root end, lb-sec^2

SECOND MOMENT

Blade second mass moment (moment of inertia) about blade root end, lb-ft-sec^2

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GAMMA   Blade Lock Number, γ, non-dimensional, defined by

$$\gamma = \frac{\rho a c R^4}{I_b}$$

A1S FLAPPING
Longitudinal (cosine component) of blade flapping, positive for blade flap up over nose, deg.

B1S FLAPPING
Lateral (sine component) of blade flapping, positive for flap up over left side of aircraft, deg.

FORCES AND MOMENTS IN BODY AXIS

This section summarizes the forces and moments acting on the body of the aircraft. The individual forces and moments are given in the body axis system and summarized in both body and inertial axis systems. The rows of forces and moments are:

X FORCE (LBS)   Positive forward

Y FORCE (LBS)   Positive toward right

Z FORCE (LBS)   Positive downward

L MOMENT (FT-LBS) Roll moment, positive right side down

M MOMENT (FT-LBS) Pitch moment, positive nose up

N MOMENT (FT-LBS) Yaw moment, positive clockwise (nose right)

The column headings are:

ROTOR   Loads generated by the main rotor

BODY AERO   Aerodynamic loads on the body

BODY INERTIAL   Inertial loading on the body, including gravity force

TAIL   Loads generated by tail rotor

RESIDUAL   Used only in the transient mode. The sum of the previous four elements calculated for the last steady state revolution before beginning the transient response. The residual values are subtracted from the four load elements in the transient condition. The residual may be considered as a tolerance on steady state

RESIDUAL - cont'd   trim. Its use prevents accelerations of the body until
a load variation occurs in the transient state. The
residual values should be small for a true steady state
condition.

TOTALS-   The total loads in the body axis including residual
BODY AXIS   loads in the transient state, excluding them in the
steady state

INERTIAL AXIS   The total loads transformed to the inertial axes.

SPATIAL COORDINATES

This section describes the motions of the aircraft. For the steady state
or trim mode of operation it displays only the forward speed (X velocity), the
trim attitude, and angular accelerations resulting from the moment unbalances
on the aircraft. The first line describes the following:

PSI   The azimuth angle of the first or reference blade, deg.

GUST AT BODY   Gust velocity acting on the body, positive upward,
ft/sec.

GUST AT TAIL   Gust velocity acting on the tail rotor, positive
upward, ft/sec.

TRIM DERIVATIVES

This section defines the changes in cyclic and collective pitch to be
used in the next iteration in order to obtain the desired trim values for
flapping and rotor Z force. The first matrix defines the partial derivatives
being used as follows:

<div align="center">

PARTIAL MATRIX DEPENDENT ACROSS

$$\frac{\Delta a_{1_s}}{\Delta A_{1_s}} \qquad \frac{\Delta b_{1_s}}{\Delta A_{1_s}} \qquad \frac{\Delta F_z}{\Delta A_{1_s}}$$

$$\frac{\Delta a_{1_s}}{\Delta B_{1_s}} \qquad \frac{\Delta b_{1_s}}{\Delta B_{1_s}} \qquad \frac{\Delta B_{1_s}}{\Delta B_{1_s}}$$

$$\frac{\Delta a_{1_s}}{\Delta_{\theta 75}} \qquad \frac{\Delta b_{1_s}}{\Delta_{\theta 75}} \qquad \frac{\Delta F_z}{\Delta_{\theta 75}}$$

Units are in degrees and pounds.

</div>

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The next matrix is simply the inverse of the above or

INVERSE OF PARTIALS

(NOTE: $\frac{\Delta X}{\Delta Y}$ does not necessarily imply $1/\Delta Y/_{\Delta X}$

$$\frac{\Delta A_{1_s}}{\Delta a_{1_s}} \qquad \frac{\Delta A_{1_s}}{\Delta b_{1_s}} \qquad \frac{\Delta A_{1_s}}{\Delta F_z}$$

$$\frac{\Delta B_{1_s}}{\Delta a_{1_s}} \qquad \frac{\Delta B_{1_s}}{\Delta b_{1_s}} \qquad \frac{\Delta B_{1_s}}{\Delta F_z}$$

$$\frac{\Delta_{\theta 75}}{\Delta a_{1_s}} \qquad \frac{\Delta_{\theta 75}}{\Delta b_{1_s}} \qquad \frac{\Delta_{\theta 75}}{\Delta F_z}$$

This matrix is multiplied by the desired changes in a_{1_s}, b_{1_s} and F_z, which are given in that order on the next line of output headed DESIRED CHANGES. The resulting changes in A_{1_s}, B_{1_s} and $\theta 75$ are given on the final line, also entitled DESIRED CHANGES. For the final pass, these changes are not implemented. They are printed out as a measure of the trim deviation.

HARMONICS OF FLAPPING

This section gives the harmonics of the flatwise slope of each blade segment, in degrees. Segment non-dimensionalized radius is given in the left column and the A_n and B_n components of slope for the first ten harmonics are displayed.

TRANSIENT RESPONSE

The response of all blades in the transient mode of operation is shown. The azimuth angle of each blade is shown at the start with the corresponding response information. This is followed by a summary of loads and airframe response. The output parameters are all as previously described.

TRANSIENT RESPONSE SUMMARY

The detailed transient response is followed by a summary showing the variation of key parameters with time, when time is defined by the azimuth angle of reference blade. The columns show for the reference blade:

1) Azimuth angle, deg.

2) Root flatwise stress, psi

TRANSIENT RESPONSE SUMMARY (cont'd)

3) Flatwise stress at station 8, psi

4) Root torsion moment, in-lb

5) Rotor Z force, lb

6) Body aerodynamic Z force, lb

7) Total Z force on the body, lb

8) X force on the aircraft, inertial axes, lb

9) Y force on the aircraft, inertial axes, lb

10) Z force on the aircraft, inertial axes, lb

11) Roll moment on the aircraft, inertial axes, ft-lb

12) Pitch moment on the aircraft, inertial axes, ft-lb

13) Yaw moment on the aircraft, inertial axes, ft-lb

ine following page contains the definitions of the important output quantities and their associated sign conventions.

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DEFINITIONS AND SIGN CONVENTIONS-

***** GENERAL

ALL OUTPUTTED HARMONIC SERIES ARE IN THE FORMS-

A0 + SUMMATION (-A(N)*COSIN(N*PSI) -D(N)*SIN(N*PSI))   OR   A0 + SUMMATION (-C(N)*SIN(N*PSI) +PHI(N)))

ALL ANGLES ARE IN DEGREES UNLESS OTHERWISE INDICATED. BUT ALL MODAL AMPLITUDES AND THEIR DERIVATIVES ARE IN RADIANS

***** BLADE MOTIONS

RIGID BODY FLAPPING (BETA) AND FLATWISE BENDING (QW)	- POSITIVE UP
RIGID BODY IN-PLANE (LEAD) AND EDGEWISE BENDING (QV)	- POSITIVE FORWARD
TORSIONAL DEFLECTIONS (QT)	- POSITIVE LEADING EDGE UP

***** AZIMUTHAL PRINTOUTS

ITEM	UNITS	POSITIVE	ITEM	UNITS	POSITIVE
BETA(LOCAL)	DEGREES	UP	XCEN	NDR	---
VERT. DEF.	FEET	UP	VAR. LAMBDA	NDO	UP
LAG ANGLE	DEGREES	AFT	PHI	DEGREES	LEADING EDGE UP
INPLANE DEF.	FEET	FORWARD	ALPHA	DEGREES	LEADING EDGE UP
TORSION DEF.	DEGREES	LEADING EDGE UP	MACH NO.	ND	---
BR STRESS	P.S.I.	---	CL	ND	UP
FLAT STRESS	P.S.I.	TENSION ON BOTTOM FIBER	CD	ND	AFT
EDGE STRESS	P.S.I.	TENSION ON AFT FIBER	CM	ND	LEADING EDGE UP
TORS. MOMENT	INCH-LBS.	LEADING EDGE UP	FB. AERO. LOAD	LBS./INCH	UP
STATION	INCHES	---	FV. AERO. LOAD	LBS./INCH	AFT
			TORS. AERO. MOM.	INCH-LBS./INCH	LEADING EDGE UP

***** FORCE INTEGRATION PRINTOUTS

COEFFICIENTS-- NON-DIMENSIONALIZED BY NORMAL COPTER CONVENTIONS (SEE GESSOW AND MYERS-F(C.) AND USE SIGN CONVENTIONS AS BELOW

ITEM	UNITS	POSITIVE	ITEM	UNITS	POSITIVE
X-FORCE	LBS.	FORWARD	ROLL MOMENT	FT-LBS.	RIGHT WING DOWN
Y-FORCE	LBS.	RIGHT WING	PITCH MOMENT	FT-LBS.	NOSE UP
Z-FORCE	LBS.	DOWN	TORQUE	FT-LBS.	CW (OPPOSITE OF PSI)
LIFT	LBS.	UP	BLADE PITCH MOMENT	FT-LBS.	LEADING EDGE UP
PROPULSIVE FORCE	LBS.	FORWARD	HORSEPOWER	HP	NEGATIVE = AUTO-ROTATION
ALPHA(S)	DEGREES	SHAFT AFT	EQUIV. DRAG	LBS.	AFT
VELOCITY	KNOTS	FWD. (NOTE- NOT SAME AS INPUT)	EQUIV. L/D	ND	---
CENT. FORCE	LBS.	---	EQUIV PARASITE AREA	SQ.FT.	AFT

NOTE- STRESS-MOMENT SUMMARY AREA AND HARMONICS AREAS ARE ALL LABELLED AND/OR USE UNITS/SIGN CONVENTIONS OF AZIMUTHAL PRINTOUTS

***** ROOT SHEARS AND MOMENTS

ALL SHEARS ARE IN LBS.   ALL MOMENTS ARE IN FT-LBS.

POSITIVE DIRECTIONS-
AXIAL - UP   INPLANE - CCW (+PSI)   RADIAL - OUTBOARD   LATERAL - RIGHT WING   LONGITUDINAL - AFT
YAWING - CCW (+PSI)   PITCHING - NOSE UP   ROLLING - RIGHT WING UP

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REFERENCES

a. Bergquist, R. R., and Thomas, G. C., NORMAL MODES ROTOR AEROELASTIC ANALYSIS COMPUTER PROGRAM, Sikorsky Aircraft, Division of United Aircraft Corporation; Technical Manual, January 1973.

b. Piziali, R. A., AN INVESTIGATION OF THE STRUCTUAL DYNAMICS OF HELICOPTER ROTOR, Cornell Aeronautical Laboratory, Inc; USAAVLABS Technical Report 70-24, April 1970.

c. Sopher, R., EQUATIONS OF MOTION FOR MULTI-BLADE ROTORS EMPLOYING COUPLED MODES AND HIGH TWIST CAPABILITY, January, 1975.

d. Sopher, R., and Thomas, G. C., MULTI-BLADE NORMAL MODES AEROELASTIC ANALYSIS INCLUDING FLEXIBLE SUPPORT, Sikorsky Aircraft Division of United Aircraft Corporation; Sikorsky Aircraft Internal Report, SER-50774, June, 1972.

e. Gerdes, W. H., and Tanner, W. H., GENERALIZED ROTOR PERFORMANCE METHOD, Sikorsky Aircraft Division of United Aircraft Corporation; Sikorsky Aircraft Internal Report, SER-50355, November 1964.

f. Arcidiacono,,P. J., Carta, F. O., Casellini, L. M., and Elman, H. L., INVESTIGATION OF HELICOPTER CONTROL LOADS INDUCED BY STALL FLUTTER, Sikorsky Aircraft Division of United Aircraft Corporation; USAAVLABS Technical Report 70-2, March 1970.

A 29 REV D

APPENDIX A

A listout of a complete run including the "JCL" for each of the three steps follows. While the specific "JCL" may vary from installation to installation the basic flow will remain the same. The particular "JCL" presented here is set up to run each of the steps automatically as one batch submission. An alternate form could be constructed to run each step individually. The former has the advantage of less elapsed time, the latter allows for scrutiny of each individual step before proceeding to the next,

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28JAN75   14.55:06   T60037

```
//UTC95CU   JOB  (Y141,ENGR,9,4),HERGQUIST,MSGLEVEL=1,
//  REGION=256K,CLASS=D,TIME=6M
//STEP1    EXEC  PGM=Y141
//SYSFLIB   DD   DSN=WTC98 Y141LOAD LOAD,DISP=SHR
//FT06F001  DD   SYSOUT=A
//FT07F001  DD   SYSOUT=B
//FT08F001  DD   UNIT=WORK,SPACE=(TRK,(2,1)),DCB=(RECFM=F,BLKSIZE=80)
//FT09F001  DD   UNIT=WORK,DISP=NEW,SPACE=(TRK,(5,2)),DCB=(RECFM=VBS,
//  LRECL=1103,BLKSIZE=2220)
//FT10F001  DD   UNIT=WORK,DISP=NEW,SPACE=(TRK,(5,2)),DCB=(RECFM=VBS,
//  LRECL=544,BLKSIZE=1692)
//FT11F001  DD   UNIT=WORK,DISP=NEW,SPACE=(TRK,(5,2)),DCB=(RECFM=VBS,
//  LRECL=40,BLKSIZE=84)
//FT12F001  DD   UNIT=WORK,SPACE=(TRK,2),DCB=(RECFM=VBS,LRECL=7290,
//  BLKSIZE=7294)
//FT15F001  DD   UNIT=WORK,SPACE=(TRK,(5,1)),
//  DCB=(RECFM=VBS,LRECL=152,BLKSIZE=1560)
//FT16F001  DD   UNIT=WORK,DISP=(NEW,PASS),SPACE=(TRK,(1,1)),
//  DCB=(RECFM=VBS,LRECL=468,BLKSIZE=472),DSN=&FILE15
//FT18F001  DD   UNIT=WORK,DISP=(NEW,PASS),SPACE=(TRK,(1,1)),
//  DCB=(RECFM=VBS,LRECL=72,BLKSIZE=76),DSN=&FILE18
//FT19F001  DD   UNIT=WORK,DISP=(NEW,PASS),SPACE=(TRK,(3,1)),
//  DCB=(RECFM=VBS,LRECL=64,DLKSIZE=72),DSN=&FILE19
//FT22F001  DD   UNIT=WORK,DISP=(NEW,PASS),SPACE=(TRK,(1,1)),
//  DCB=(RECFM=VBS,LRECL=552K,BLKSIZE=181,DSN=&FILE21
//FT24F001  DD   DSN=WTC98 Y141 FILE22,DISP=SHR
```

```
23JAN75        14:05:00        TC0017

1 136   -20.
1 146   1.            1.33      1.33      1.33      1.33
5 179   1.33          1.33      1.33      1.33      1.33
5 195   1.33          1.33      1.33      1.33      1.33
5 199   1.33          12        12        12        12
5 180   12            12        12        12        12
5 185   12            12        12        12        12
5 190   12            12        12        12        12
5 195   12            12        12        12        12
5 200   12            12        12        12        12
5 205   12            12        12        12        12
1 450       2
1 455       5
1 465   .0023.78      1117.     1.33      1.        20
5 500   -6.           0.        50000.    20        1.48
5 513   0.            0.        1M.       -.06
2 517   8.
2 518   1.            10.       10.
2 518       5.
1 72    2.
1 143   8000.
1 523   1.
1 5 5   -1.
1 523   6.
1 549   10000.
1 5 1   -1.
1 519   5.
1 70        2
1 98    0.
1 519   0.
2 515   15.           15.
1 95    2.
1 522   1.
-1 99   -1
-1 93-1
```

```
//STEP2  EXEC  PGM=F332
//GOFILE  DD  DSN=UTC98.F339.LOAD,DISP=SHR
//FT01F001 DD  UNIT=WORK,SPACE=(TRK,(40,10)),
//   DCB=(RECFM=VBS,LRECL=1004,BLKSIZE=5424)
//FT02F001 DD  UNIT=WORK,SPACE=(TRK,(30,10)),
//   DCB=(RECFM=VBS,LRECL=CL=4000,BLKSIZE=5444)
//FT03F001 DD  UNIT=WORK,SPACE=(TRK,(2,1)),
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=1600)
//FT14F001 DD  DSN=FILE16,DISP=(OLD,DELETE)
//FT15F001 DD  UNIT=WORK,SPACE=(TRK,(30,10)),DISP=NEW,
//   DCB=(RECFM=VBS,LRECL=1053,BLKSIZE=1392)
//FT16F001 DD  DSN=FILE16,DISP=(OLD,DELETE)
//FT17F001 DD  DSN=FILE17,DISP=(OLD,DELETE)
//FT20F001 DD  UNIT=WORK,DISP=(NEW,PASS),SPACE=(TRK,(1,1)),
//   DCB=(RECFM=FB,LRECL=544,BLKSIZE=544),DSN=&FILE20
//FT08F001 DD  SYSOUT=A
-1 99  -1
```

A3

```
7BJAN75    14:55:05    T00037

//STEP3    EXEC  PGM=Y141
//STEPLIB  DD    DSN=WTC98.Y141LOAD.LOAD,DISP=SHR
//FT06F001 DD    SYSOUT=A
//FT07F001 DD    SYSOUT=B
//FT08F001 DD    UNIT=WORK,SPACE=(TRK,(2,1)),DCB=(RECFM=F,BLKSIZE=80)
//FT09F001 DD    UNIT=WORK,DISP=NEW,SPACE=(TRK,(5,2)),DCB=(RECFM=VBS,
//               LRECL=1108,BLKSIZE=7240)
//FT10F001 DD    UNIT=WORK,DISP=NEW,SPACE=(TRK,(5,2)),DCB=(RECFM=VBS,
//               LRECL=544,BLKSIZE=10892)
//FT11F001 DD    UNIT=WORK,DISP=NEW,SPACE=(TRK,(5,2)),DCB=(RECFM=VBS,
//               LRECL=40,BLKSIZE=...34)
//FT12F001 DD    UNIT=WORK,SPACE=(TRK,7),DCB=(RECFM=VBS,LRECL=7290,
//               BLKSIZE=7294)
//FT15F001 DD    UNIT=WORK,SPACE=(TRK,(5,1)),
//               DCB=(RECFM=VBS,LRECL=1352,BLKSIZE=1356)
//FT20F001 DD    DSN=&FILE20,DISP=(OLD,DELETE)
//FT21F001 DD    DSN=&FILE21,DISP=(OLD,DELETE)
//FT22F001 DD    DSN=WTC98.Y141.FILE22,DISP=SHR
//FT25F001 DD    *
```

APPENDIX B

Additional Input for Unsteady Aerodynamics

The unsteady curve option requires the following peripheral curves in addition to the basic unsteady data.

Curve	Curve Title
ASTCN	Value of stall alpha associated with CN as function of Mach No.
RCNM	Ratio of CN stall at actual Mach no. to CN stall at Mach no. = 0.
ASTCM	Value of stall alpha associated with CM as function of Mach no.
CNREG1	Upper boundary of alpha associated with EN as a function of Mach no. to define end of unsteady region.
CNREG2	Lower boundary of alpha associated with EN as a function of Mach no. to define beginning of steady region.
CMREG1	Same comment as CNREG1 except for CM.
CMREG2	Same comment as CNREG 2 except for CM.

The area between the upper boundary of the unsteady data and the lower boundary of the steady data is a transition region. If the α, Mach number combination is in the region a linear interpolation between unsteady and steady is performed to calculate CN or CM.

In addition the maximum and minimum values of A and B (functions of $\dot{\alpha}$ and $\ddot{\alpha}$) are defined in a data statement in subroutine "AEROD". Thus if these values are to be changed the subroutine "AEROD" must be recompiled. A complete description of the mechanics of the unsteady aerodynamics may be found in reference (e).

Additional Input for Induced Velocity Calculation

The following three curves are used by the aeroelastic module to prepare data files for the calculation of induced velocities. See Appendix C. for a complete description.

Curve	Curve Title
ACLZ	Alpha for zero C_L vs. Mach No.
ACLM	Alpha for max C_L vs. Mach No.
ASLP	Lift curve slope vs. Mach No.

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A sample listout of all necessary data assuming a 0012 airfoil follows. The "JCL" to set this data up on File 22 is also included. However this data may be loaded directly into the program via the card reader if desired; see location 135 on page 19.

$$\frac{B2}{PAGE}$$

27 JUN 75   14:22:55   T00037

```
//ALPHA EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSUT2 DD DSN=WTC98 V141.FILE22.INIT=TSO.DISP=(NEW.CATLG),
// SPACE=(TRK.(5.2)),DCB=(RECFM=FB.LRECL=80.BLKSIZE=3120)
//SYSIN DD DUMMY
//SYSUT1 DD *
CRUNST
UNSTEADY ON DATA
ALPHA PP NON-DIMENSIONAL BLADE NORM FORCE COEF.
```

SER-50910

27JAN75   14:22:55   TB0037

27JAN75   14:22:55   T00037

27JAN75   14:22:55   T00037

UNSTEADY CM DATA

UNSTEADY CM NON-DIMENSIONAL BLADE PITCH MOM COEF.

27JAN75   14:24:15   T00037

27JAN75   14:22:55   T00037

27JAN75 14:22:55 T60037

NPTS   9.   ALPND   ALPHA   20.
-.01   -.15   -.049   -.21   .004   -.248   -.001   -.182
 0   -.156   -.007   -.14   .004   -.096   .007   -.09
 .01   -.065   .001

NPTS   9.   ALPND   ALPHA   20.
-.01   -.105   -.025   -.155   .004   -.225   -.001   -.125
 0   -.1   -.007   -.07   .004   -.08   .007   -.03
 .01   -.07   .001

NPTS   9.   ALPND   ALPHA   20.
-.01   -.07   -.01   -.12   .004   -.18   -.001   -.112
 0   -.085   -.007   -.04   .004   -.09   .007   -.1
 .01   -.095   .001

NPTS   9.   ALPND   ALPHA   20.
-.01   -.07   0   -.095   .004   -.115   -.001   -.115
 0   -.092   -.007   -.075   .004   -.095   .097   -.115
 .01   -.103   .001

NPTS   9.   ALPND   ALPHA   20.
-.01   -.06   .01   -.072   .004   -.087   -.001   -.082
 0   -.068   -.007   -.052   .004   -.11   .007   -.13
 .01   -.11   .001

NPTS   9.   ALPND   ALPHA   20.
-.01   -.07   .04   -.075   .004   -.035   -.001   -.065
 0   -.04   -.007   -.049   .004   -.125   .007   -.134
 .01   -.13   .001

NPTS   9.   ALPND   ALPHA   20.
-.01   -.004   .04   -.053   .004   -.11   -.001   -.034
 0   -.055   -.007   -.061   .004   -.106   .007   -.097
 .01   -.090   .001

NPTS   9.   ALPND   ALPHA   22.
-.01   -.27   -.04   -.297   .004   -.21   -.001   -.142
 0   -.15   -.007   -.127   .004   -.089   .007   -.087
 .01   -.075   .001

NPTS   9.   ALPND   ALPHA   22.
-.01   -.215   -.025   -.275   .004   -.207   -.001   -.197
 0   -.107   -.007   -.03   .004   -.08   .007   -.092
 .01   -.095   .001

NPTS   9.   ALPNC   ALPHA   22.
-.01   -.112   -.01   -.147   .004   -.23   -.001   -.125
 0   -.175   -.03   -.065   .004   -.1   .007   -.105
 .01   -.148   .001

NPTS   9.   ALPND   ALPHA   22.
-.01   -.155   -.025   -.031   .004   -.09   -.001   -.182
 0   -.163   -.007   -.107   .004   -.135   .004   -.12
 .01   -.135   .001

NPTS   9.   ALPND   ALPHA   22.
-.01   -.112   .01   -.091   .004   -.11   -.001   -.082
 0   -.135   -.007   -.117   .004   -.165   .007   -.175
 .01   -.173   .001

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NPTS   5.   ALPHD   ALPHA   24   -1.21
.01   -.33   -.13   -.094
.0   -.118   -.001   -.007
.01   -1   .007

NPTS   9   ALPND   ALPHA   21   -.092
-.01   -.275   -.055   -.152   -.001 -.115
.0   -.115   -.05   -.12   .007
.01   -.11

NPTS   5   ALPND   ALPHA   24   -.13
-.01   -.245   -.58   -.127   -.001 -.107
.0   -.55   -.115   -.155   .007
.01   -.144

NPTS   9   ALPND   ALPHA   24   -.19
-.01   -.225   -.252   -.214   -.001 -.122
.0   -.115   -.152   -.127   .007
.01   -.113

NPTS   9   ALPND   ALPHA   24   -.225
-.01   -.175   -.224   -.186   -.001 -.142
.0   -.147   -.2   -.152   .007
.01   -.17

NPTS   5   ALPND   ALPHA   24   -.235
-.01   -.167   -.267   -.09   -.001 -.205
.0   -.225   -.19   -.19   .007
.01   -.202

NPTS   3   ALPND   ALPHA   24   -.4
-.01   -.055   -.09   -.114   -.001 -.235
.0   -.14   -.254   -.234   .007
.01   -.225

ASTCM
VALUE OF STALL ALPHA AS FUNCTION OF MACH NO., BLADE PITCHING MOMENT
MACH NUMBER   ALPHA STALL
NPTS   7.   13.5   13.5   .3   12.5   .4   16.
             9.9   7   1   7

RCCM
RATIO OF CN STALL AT MACH 10 CN STALL AT MACH#8
MACH NUMBER   RATIO
NPTS   7.   1.3476   .2   1   .3   .4   .8114
              .8   .219   1   .219 .4

ASTCN
VALUE OF STALL ALPHA AS FUNCTION OF MACH NO., BLADE NORMAL FORCE COEFF
MACH NUMBER   ALPHA STALL
NPTS   9   10   24.1   3   10.4   .4   8.4
             6.5   4.8   .7   2.9   .3   2.0
             2   0.0

CNMGG1
UPPER BOUND OF REGION 1 - UNSTEADY DATA, FIG 31-1, CN
               ANG OF ATTACK, ALPHA
MACH NUMBER
NPTS   10   24.1   8.2   0.3   25.2   0.5   16.0
              1.5   0.6   0.7   2.9   0.8   2.0
              2.0   0.85

CNMGG2
LOWER BOUND OF REGION 2 - STEADY DATA, FIG 31-1, CN

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MACH NUMBER   ANG OF ATTACK , ALPHA
NPTS   10.
0 0   27.0   0 2   27.0   0 3   28.1   17.5
0 51   6.5   8.6   4.8   0.7   2.9   2 0
0.34   2.0   0.85   0.0

CMREG1
UPPER BOUND OF REGION 1 - UNSTEADY DATA , FIG 31-2 , CM
MACH NUMBER   ANG OF ATTACK , ALPHA
NPTS   7.
0 0   24.3   0 2   24.3   0 5   21.0   11.6
0.6   10.6   0 33   13.4   0 84   0.0

CMREG2
LOWER BOUND OF REGION 2 - STEADY DATA , FIG 31-2 , CM
MACH NUMBER   ANG OF ATTACK , ALPHA
NPTS   6.
0 0   27.0   0 2   27.0   0 3   26.0   22.0
0 51   11.6   0.6   16.5   0.63   10.4   0.0

CLSP
UNIVARIATE SPAR LIFT COEFFICIENT DATA
ALPHA   CL
NPTS   36.
0. 0   0 0   15 0   1 775   19.0   0 95   20 0   0 83
0 0   0.783   22.0   0.781   23.0   0.790   25 0   0 86
0.37   0.967   38.0   1 68   35.0   1 2   38 0   1.255
1.700   1 275   43 0   1 29   45.0   1 292   47 0   1 29
1.718   1 262   55 0   1 125   115.0   1 82   110 0   1 86
1.593   1 879   123 0   1 697   127.0   1 902   129 0   1 3
1.45   1 879   140.0   1 84   145 0   1 782   150 0   1 675
1.21   1 595   152 0   0 83   165.0   0 870   167 0   1 111
0.465   0 142   175.0   0.16   176.5   0 15   180 0   0 0
0.168

CDSP
UNIVARIATE SPAR DRAG COEFFICIENT DATA
ALPHA   CD
NPTS   27.
0. 0   0 151   6 0   0 152   11.0   0 165   16 0   0.192
0 0   0.221   36.0   1 102   41.0   1 108   46 0   1 48
0.37   1 541   51 0   1 605   56 0   1 675   50 0   1 70
1.700   1 700   61 0   1 711   64.0   1 721   55 0   1 732
1.718   1 718   71 0   1 712   76.0   1 679   84 0   1 643
1.593   1 593   96 0   1 523   101.0   1 555   104 0   1 523
1.45   1 45   121 0   1 462   106.0   1 76   131 0   1 292
1.21   1 21   141 0   1 095   151.0   0 795   156 0   0 625
0.465   0 465   166 0   0 343   171.0   0 251   170 0   0 190
0.168

CMSP
UNIVARIATE SPAR PITCHING MOMENT COEFFICIENT DATA
ALPHA   CM
NPTS   36.
0 0   0 0   15 0   0 5   19 0   0 72   20 0   0.307
0.28   0 28   30.0   0 20   35 0   0 704   40 0   0 34
0.37   0 37   55 0   0 722   55 0   0 38   60 0   0 764
1.333   0 333   78.0   0 296   75 0   0 266   80 0   0 228
0.213   0 213   90.0   0 19   90 0   0 168   100 0   0.148
1.107   0 107   120 0   0 066   125 0   0 045   130 0   0 025
0.063   0 063   143 0   0 017   145 0   0 037   150 0   0 057
0.09   0 09   161 0   0 09   165 0   0 070   167 0   0 052
0.160

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178 0   - 023   175.0   0.2   177.0   0.02   180 0   0.0

COD4T

BIVARIANT CD VS ALPHA CURVE

ALPHA   DRAG COEF.

NPTS   #20.

NPTS   #25

NPTS   #25

NPTS   #25

NPTS   #25.

NPTS   #21

SER-50910

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NPTS	#21									
4.4000	.0007	4.8000	.0109	5.2000	.0125	6.0000	.0180
6.0000	.0308	7.7000	.0270	8.0000	.0508	8.9000	.0580
10.6000	.1200	11.4000	.1598	12.0000	.1700	14.0000	.2100
17.0000	.2300	20.0000	.2700	22.0000	.2700	26.0000	.52??
30.0000	.7800						

NPTS	#14	MACH #	.7000					
2.0000	.0100	2.0000	.0110	2.6000	.0130	1.6000	.0090
4.4000	.0200	3.6000	.0270	4.4000	.0150	3.0000	.0170
5.2000	.0600	6.2000	.0670	6.9000	.0800	7.0000	.0440
9.0000	.1220	10.0000	.1400	11.0000	.1760	12.0000	.0340
30.0000	.1970							.1970

NPTS	#LE	MACH #						
.0000	.0102	.7500	.0115	1.0000	.0130	2.0000	.3200
2.6000	.0263	3.0000	.0322	3.4000	.0490	3.8000	.0500
5.2600	.0590	4.4000	.0640	4.8000	.0720	5.0000	.0775
	.6626	5.6000	.0910	6.0000	.0960	5? .0367	.0?30

NPTS	#14	MACH #						
.0187	.4000	.0195	.9000	.0215	1.0000	.9230
.0200	2.2600	.0430	2.8000	.0530	2.4000	.0660
.0600	4.6000	.0940	5.2000	.4060	5.6000	.1130
.1200	30.0000	.1200			

NPTS	#7	MACH #						
.0700	1.0000	.0760	2.0000	.0900	3.0000	.1380
.1230	5.0000	.1460	30.0000	.1460		

NPTS	#7	MACH #						
.0700	2.0000	.0700	2.0000	.0900	3.0000	.1030
.1220	5.0000	.1400	30.0000	.1400		

CLDAT
BIVARIANT CL VS ALPHA CURVE
ALPHA   LIFT COEF

NPTS	#24	MACH #	.0000						
15.0000	.6000	10.0000	-1.6000	13.6000	-1.2000	15.0000	-1.0000
50.0000	.6600	25.0000	.6500	35.6000	-1.1000	4?.0000	-1.1600
105.0000	1.1000	62.0000	.8810	76.6000	-1.5100	98.0000	-1.0500
140.0000	.7900	120.0000	-.7900	130.0000	-1.9700	135.0000	-1.0490
150.0000	-1.6600	145.0000	-1.0250	150.0000	-1.9000	156.0000	-1.7000
160.0000	-.6600	168.0000	-1.6400	172.0000	-1.7890	180.0000	.0000

NPTS	#24	MACH #	.0000						
15.0000	.6600	10.0000	.6600	12.0000	-1.2000	13.0000	-1.0000
50.0000	-1.1000	35.0000	.6600	26.6000	-1.1600	15.0000	-1.1000
105.0000	.8990	62.0000	.8810	76.0000	-1.5100	90.0000	.8500
140.0000	-1.0500	120.0000	-.7900	130.0000	-1.9700	155.0000	-.8200
158.0000	-1.6600	145.0000	-1.2250	150.0000	-1.9600	156.0000	-1.7000
		160.0000	-.6400	172.0000	-1.7300	180.0000	.0000

NPTS	#20	MACH #	.0000						
13.0000	.6000	11.0000	.1600	12.0000	-1.2000	13.0000	-1.5600
15.0000	1.3600	14.0000	.3300	14.5000	-1.1600	15.0000	-1.2000
15.0000	.6600	16.0000	.9500	17.0000	.9700	16.0000	-.8500
19.0000	.8400	20.0000	.8100	11.0000	.9000	22.0000	.8350
24.0000	.8250	26.0000	.8800	28.0000	.9320	30.0000	.9500

NPTS	#16	MACH #	.0000						
12.5600	.2720	10.0000	.1900	11.0000	.1900	12.0000	1.2500
15.0000	1.0900	13.0000	.2600	13.5000	.2600	14.0000	1.2200
19.0000	.8250	16.0000	.9600	17.2000	.9100	18.0000	1.8550
		20.0000	.8100	22.0000	.8700	30.0000	1.0150

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```
NPTS  #14
         .0000    8.0000    3.0000   10.0000   1.0000
 11.    .0000   12.0000   13.0000   16.0000   1.0050
 17.    .0000   18.0000   19.0000   20.0000    .3280
 22.    .0000   20.0000

NPTS  #17    MACH #
         .0000    6.0000    7.0000    8.0000    .9280
  9.    .0000   10.0000   11.0000   12.0000   1.0000
                         .0000   16.0000    .8450
 19.    .0000   20.0000   21.0000   22.0000    .8470
 30.    .0000   1.0000

NPTS  #16    MACH #
         .0000    5.0000    6.0000    8.0000    .8700
 10.    .0000   12.0000   14.0000   16.0000    .9200
 17.    .0000   18.0000   19.0000   20.0000    .5500
 21.    .0000   22.0000   27.0000   30.0000   1.1700

NPTS  #9     MACH #
         .0000    2.0000    4.0000    5.0000    .6750
 10.    .0000   17.0000                         .9400

NPTS  #12    MACH #
         .0000    1.0000    2.0000    2.5000    .4700
         .0000    4.0000    4.0000    4.5000    .6600
  5.    .0000    5.0000    6.0000   30.0000    .7450

NPTS  #1     MACH #
         .0000    2.0000    3.0000    5.0000    .6900
  6.    .0000   30.0000

NPTS  #7     MACH #
         .0000    1.0000    2.0000    3.0000    .3000
  5.    .0000

NPTS  #4     MACH #
         .0000

NPTS  #3     MACH #
         .0000
```

CMDAT
DIVERGENT CM VS ALPHA CURVE
ALPHA   LIFT COEF.

```
NPTS  #33    MACH #
         .0000    6.0000    8.0000
 10.    .0000   12.0000   13.0000
 13.    .0000   15.0000   15.0000
 16.    .0000   20.0000   24.0000
 27.    .0000   35.0000   45.0000
 50.    .0000   95.0000  110.0000
125.    .0000  145.0000  150.0000
154.    .0000  165.0000  174.0000
190.    .0000

NPTS  #25    MACH #
         .0000    6.0000    8.0000
 10.    .0000   12.0000   13.0000
 12.    .0000   15.0000   15.0000
 16.    .0000   20.0000   24.0000
 27.    .0000   95.0000   45.0000
 60.    .0000   95.0000  110.0000
125.    .0000  145.0000  150.0000
154.    .0000  165.0000  174.0000
190.    .0000

NPTS  #21    MACH #
         .0000    4.0000    6.0000    8.0000    .0000
```

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| .0000 | .0000 | 1.0000 | -.0500 | 4.0000 | -.1000 | 8.0000 | -.1300 |
| .30 0000 | -.1300 | | | | | | |

BRUFM

UTTAS BODY NORMAL FORCE   BODY NORMAL FORCE
FUSELAGE ANGLE OF ATTACK
NPTS   16

-180.	.0	-150.	-170.	-135.	-595.	-64.	-595.
-45.	-242.	-30.	-105.	-20.	-50.	-10.	-25.
0	.0	10.	25.	20.	50.	30.	104.
45.	213.	135.	213.	150.	100.	100.	.0

BLONG

UTTAS BODY LONGITUDINAL FORCE
FUSELAGE ANGLE OF ATTACK BODY LONGITUDINAL FORCE
NPTS   17

-180.	-24.	-100.	-24.	-135.	17.	-120.	-12.
-90.	0	-50.	12.	-43.	17.	-20.	24.
0	24.	20.	24.	45.	17.	60.	12.
180.	-24.	120.	-12.	135.	-17.	150.	-24.

BPIT

UTTAS BODY PITCHING MOMENT
FUSELAGE ANGLE OF ATTACK BODY PITCHING MOMENT
NPTS   17

-180.	0	-120.	2750.	-90.	4500.	-34.	-400.
-90.	-400.	-10.	-255.	.3	.0	10.	250.
20.	450.	30.	450.	80.	-1075.	106.	-1075.
180.	.0						

BSIDF

UTTAS BODY SIDE FORCE   BODY SIDE FORCE
BODY SIDESLIP ANGLE
NPTS   15.

-180.	.0	-150.	115.	-135.	211.	-45.	211.
-30.	116.	-20.	70.	-10.	35.	.0	.0
10.	-35.	20.	-70.	30.	-116.	45.	-211.
135.	-211.	150.	-115.	180.	.0		

BYAW

UTTAS BODY YAWING MOMENT
BODY SIDESLIP ANGLE   BODY YAWING MOMENT
NPTS   11

-180.	0	-150.	-1170.	-80.	-1170.	-36.	270.
-30.	270.	.0	.4	18.	-270.	36.	-270.
80.	1170.	100.	1170.	180.	.0		

DWNHT

TAIL DOWNWASH   EKHT
ZTAP
NPTS   8.

| 0 | 2.2 | .2 | 1.82 | .4 | 1.47 | .5 | 1.3 |
| .0 | 1.17 | .7 | 1.05 | .8 | 1.03 | 1. | 1. |

QTHIL

UTTAS TAIL DYNAMIC PRESSURE RATIO
FUSELAGE ANGLE OF ATTACK TAIL DYN PRESS. RATIO
NPTS   7.

| -180. | 1. | -45. | -10. | .0 |
| 10. | .9 | 45. | 180. | 1. |

NFHT

UTTAS TAIL NORMAL FORCE

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TAIL EFF.ANGLE OF ATTACK   TAIL NORMAL FORCE
NPTS   13.
-180.   0   -150.   -.8   -120.   -1.2   -60.   -1.2
-24.   -.73   -18.   -.98   0   .9   18.   .73
24.   .73   60.   1.2   120.   1.2   150.   .84
180.   0

NFVI

UITAS FIN NORMAL FORCE   FIN NORMAL FORCE
FIN ANGLE OF ATTACK
NPTS   13.
-180.   0   -150.   -.3   -120.   -1.2   -60.   -1.2
-25.   -1.02   -20.   -.95   0   0   20.   .95
25.   1.02   60.   1.2   120.   1.2   150.   .88
180.   0

WNGNF
WING NORMAL FORCE   CNW
ALFW
NPTS   22.
-180.   0   -160.   .524   -140.   -.831   -120.   -1.28
-60.   -1.28   -30.   -.955   -26.   -1.05   -22.   -1.182
-18.   -1.127 -14.   -.914   -18.   -.65   10.   .65
14.   .914   18.   1.127   22.   1.152   26.   1.85
30.   .955   60.   1.28   120.   1.28   140.   .331
160.   .524

WNGCF
WING CHORDWISE FORCE   CCW
ALFW
NPTS   31.
-180.   .02   -160.   -.064   -140.   -.087   -120.   -.032
-90.   0   -60.   0   -30.   -.055   -26.   -.133
-22.   .198   -18.   -.198   14.   -.134   -10.   -.064
-6.   -.167   -4.   .007   -2.   .007   0.   -.01
2.   .007   4.   .002   6.   .0167   10.   -.064
14.   .134   18.   .198   22.   .198   26.   -.172
30.   .066   60.   0   90.   0   120.   -.082
140.   -.087   160.   .064   180.   .02

WNGPM
WING PITCHING MOMENT   CMW
ALFW
NPTS   24.
-180.   0   -150.   .245   -140.   .320   -120.   .308
-90.   .371   -60.   .268   -30.   .1x   -26.   .121
-22.   .11   -18.   0   -10.   -.0465 -6.   -.005
6.   .006   6.   .0065   18.   0   0.   0
26.   -.121   26.   -.132   60.   -.268   90.   -.11
120.   -.208   120.   -.32   160.   -.245   180.   0

WNGROL
WING ROLLING MOMENT   CRLW
ALFW
NPTS   6.
-180.   0   -150.   .0369   -30.   .0363   30.   .0369
150.   -.0369 180.   0

ACL2
ALPHA FOR ZERO CL   ALPHA
MACH
NPTS   12.

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```
0        .0      0.      .0      0.      .0      0.
4        0.      5.      .0      5.0     .7      .0
5R       0.      9.      1.0     9.      .2      .0

ALIM
ALPHA FOR MAX CL
MACH                              MLPHH
NPTS     12.
H        13.8    .1      13.8    .2      13.5    .3      12.5
4        12.     .5      8.      .6      7.      .7      5.9
8        5.      .9      5.      1.0     5.      .2

ASLP
LIFT CURVE SLOPE                  A
MACH
NPTS     12.
0        5.73    .1      5.73    .26     6.68    .37     6.3
4        6.55    .5      7.85    .6      7.73    .7      3.9
8        9.9     .9      5.73    1.      5.73    .2      5.73
END
/*
```

APPENDIX C

UARL Prescribed Wake Rotor

Inflow Program (Single Rotor Version)

by

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Supervisor, Rotary Wing Technology

and

T. Alan Egolf

Assistant Research Engineer

Prepared by

United Aircraft Corporation, Research Laboratories

East Hartford, Connecticut

February 1975

CONTENTS OF USER'S MANUAL FOR THE
UARL PRESCRIBED WAKE ROTOR INFLOW PROGRAM
(SINGLE ROTOR VERSION)

TECHNICAL APPROACH

General Description and Assumptions

The UARL Prescribed Rotor Wake Inflow Program (hereafter referred to as the rotor inflow program) computes the circulation and inflow distributions along the blades based on a prescribed wake model and a number of assumptions regarding the aerodynamics at each blade section. The section operating conditions are generally prescribed from blade motion and control information obtained from a separate blade response program. The wake model is either generated internally in the computer program (undistorted wake) or prescribed from a separate program. Procedures have been developed for coupling the programs together in a linked manner as shown in Figure 1. Descriptions and results pertaining to the development and application of the rotor inflow program in combination with wake geometry and blade response programs are presented in References 1 through 4.

Input to the rotor inflow program is obtained from the coupled mode dynamic analysis. The latter program is often referred to as deck or program Y141 in this appendix. This Y141 should not be confused with the uncoupled aeroelastic program described in Reference d of the text. The Y141 referred to in this appendix is the coupled mode dynamic analysis described in Reference c.

Briefly, the mathematical model in the rotor inflow program consists of the representation of each blade by a segmented lifting line, and the helical wake of the rotor by discrete segmented vortex filaments consisting of trailing vorticity which result from the spanwise variation of bound circulation. The circulation of the wake for each blade changes with azimuth position and is periodic for each rotor revolution. The blades are divided into a finite number of radial segments, and the induced velocity at the center of each selected blade segment is computed by summing the contributions of each bound and trailing wake segment. The contribution of each vortex segment is obtained through use of the Biot-Savart equation which expresses the induced velocity in terms of the circulation strength of the vortex segment and its geometrical position relative to the blade segment at which the induced velocity is desired. The bound circulation distribution is determined by relating the wake circulations to the bound circulations, expressing the wake induced velocities in terms of the unknown bound vortex strengths by means of the Biot-Savart equation, and developing a set of simultaneous equations relating the bound circulation and local blade angle of attack at each blade segment. These equations thus involve the known flight condition, wake geometry, lift-curve slope, and blade motion and control parameters and the unknown bound circulation values. Solution of these equations yields the desired bound circulation values, which, when combined with the appropriate geometrical relations in the Biot-Savart law, produce the required induced velocity distribution.
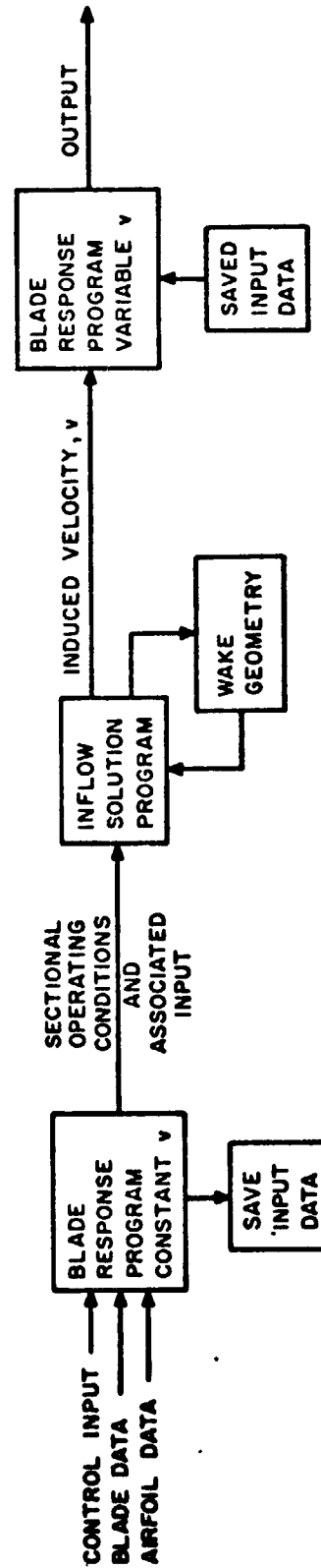
Figure 1. Flow Chart of Rotor Inflow Program
Combined with Blade Response and
Wake Geometry Programs

INPUT

SECTION
PARAMETERS
COMPUTED

WAKE
GEOMETRY
OBTAINED

GEOMETRIC
COEFFICIENTS
CALCULATED

CIRCULATION
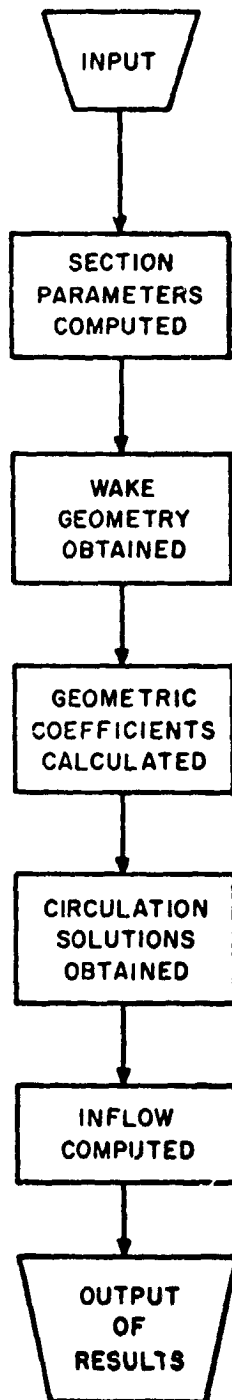SOLUTIONS
OBTAINED

INFLOW
COMPUTED

OUTPUT
OF
RESULTS

Figure 2. Sequence of Program Operations

A simplified flow diagram showing the sequence of operations of the program is presented in Figure 2. The section parameters (airfoil characteristics and geometric angle of attack) are computed. The blade-wake geometry is formulated. The wake influence coefficients (geometric coefficient) at the blades are calculated using the Biot-Savart law. Numerical techniques are used to solve the circulation matrix. Finally, the inflow (induced velocities) are computed.

The fundamental background for the analytical formulation used in the computer program was obtained from the technical approach described by Piziali and DuWaldt in Reference 5. Although a new computer program has been developed, and many modifications and refinements have been incorporated, many of the fundamental assumptions are retained from that reference.

The rotor inflow program is based on the following formulation and assumptions:

1. Each blade is represented by a lifting line (bound vortex) divided into a finite number of segments (blade segments) each having a different circulation strength (see Figure 3). The aerodynamic characteristics at the centers of each segment are assumed to be representative of the entire segment over a finite azimuth interval. The use of lifting line rather than lifting surface theory results in the satisfying of the aerodynamic boundary conditions at only one point on the chord (quarter chord point) of each blade segment.

2. The wake is represented by a finite number of vortex filaments trailing from the blade segment boundaries. Each filament is divided into straight segments, the lengths of which are determined by a specified wake azimuth interval which is equivalent to the azimuth interval of each blade (see Figure 3). The circulation strength of each trailing vortex segment is constant along its length, and is equivalent to the difference between the circulation values of its adjacent bound vortex segments in accordance with the Helmholtz laws of conservation of vorticity. The circulation strengths of different vortex segments along a vortex filament vary in accordance with the variation of the bound circulations with azimuth position.

3. Viscous dissipation effects on the wake circulation strengths are neglected in that the circulation of a given wake segment is constant with time. However, the number of wake revolutions retained in the analysis can be limited to evaluate an abrupt dissipation of the wake. Also, the viscous rollup of the tip vortex can be approximated by combining tip filaments beyond a prescribed rollup azimuth interval. In addition, a vortex core size is assigned to each vortex filament. Potential theory is assumed to apply outside the vortex core. Inside the vortex core zero flow is assumed.

4. It is assumed that the rotor is operating in steady-state flight. The inflow and wake from each blade is assumed to be periodic with blade spacing. This is, the inflow and wake geometry is the same for each blade when at a specific azimuth position.

⊙ BLADE SEGMENT CENTERS (INFLOW STATIONS)
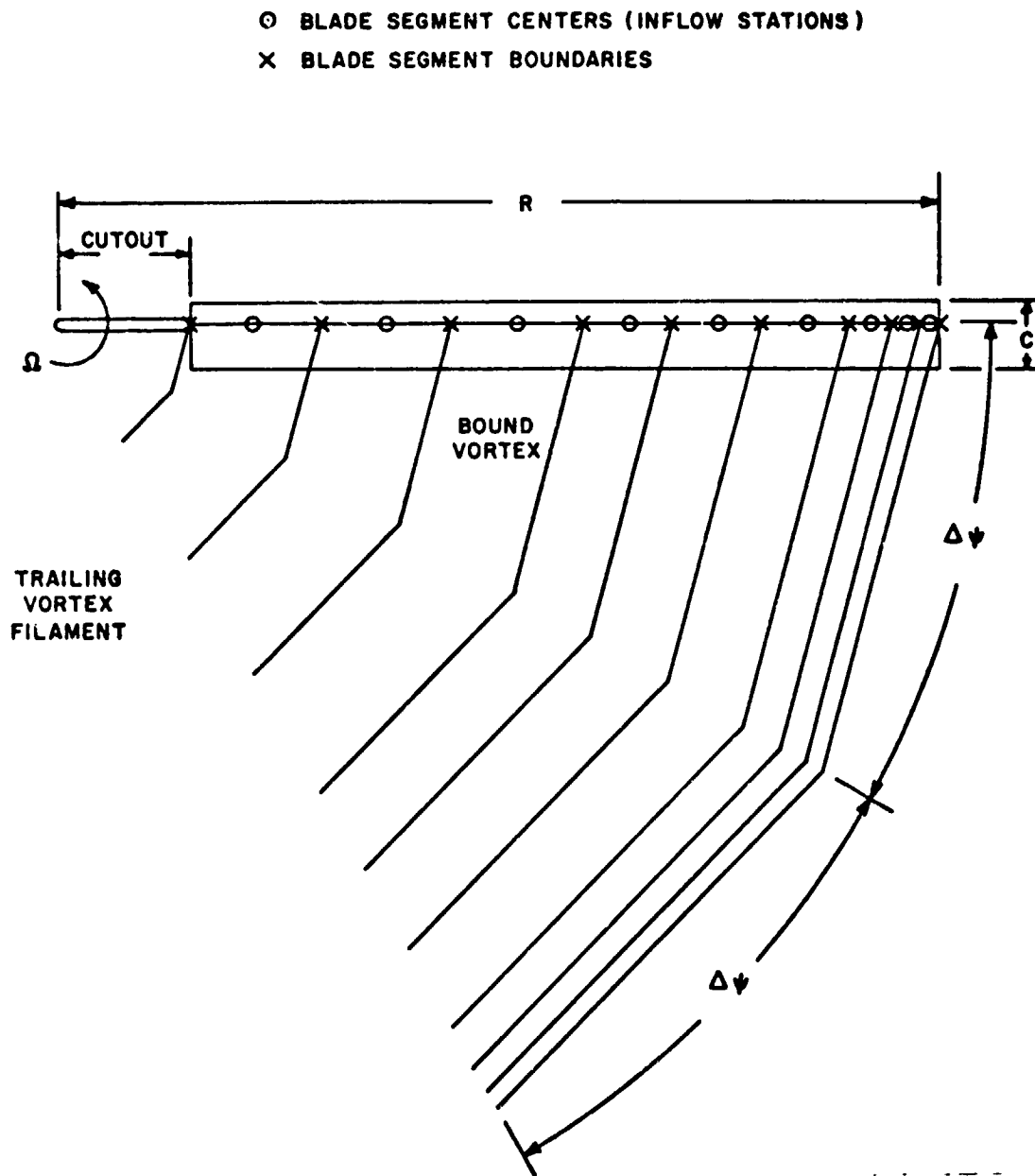✕ BLADE SEGMENT BOUNDARIES

Figure 3. Representation of Blade and Wake by
Bound and Trailing Vortex Segments

5. Shed wake segments (segments normal to the trailing wake segments mentioned above) arising from the time rather than radial variations of bound vorticity, are not included in the wake model. Although this omission technically violates the Helmholtz law, it is believed that a more accurate representation of the shed wake effects is obtained through the use of experimental unsteady airfoil characteristics in the analysis. This implies that the primary effects of the shed vorticity are those associated with the shed wake immediately behind the blade, and thus can be approximated by those of a fixed-wing type of wake. Miller (Reference 6) shows that this is reasonable at rotor advance ratios usually of interest. This approach not only permits a factor of two reduction in computer time and prevents unrealistic results associated with a finite filament wake model, but more importantly, permits nonlinear unsteady stall effects to be included in a rational manner in the blade response program.

6. The wake geometry is prescribed from analytical or experimental results. Various options are available for selecting the representation of the wake model.

7. The airfoil at the blade is assumed two-dimensional (radial velocity components are neglected). For the linearized circulation solutions and associated calculations, a set of lift curve slopes, stall angles of attack, and angles of zero lift are provided which vary with Mach number. These may be based on unsteady aerodynamic data, if available, and provided directly from a blade response program. Below stall the lift curve slope is assumed constant. The blade section circulation is limited to a constant value for angles of attack above stall.

8. In the blade-wake geometry calculations the blades are assumed straight (rigid blades). However, flexibility effects may be included in the circulation solution by providing the necessary noninduced velocity at each segment associated with flexible blade motions and controls from a blade response program. Also, an anhedral tip may be prescribed.

9. Tangential induced velocity components are neglected.

10. Small angle assumptions are included in the circulation solution.

11. The aerodynamic interference effects of the rotor hub, fuselage, etc. are neglected. The rotor is assumed to be operating out-of-ground effect.

Wake Geometry

The rotor inflow program requires that the rotor wake geometry be specified in order for circulations and induced velocities to be determined. There are several alternatives for rotor wake geometry. The least complex wake geometry is a classical undistorted wake which is simply a function of the flight condition and mementum inflow velocity. The coordinates of this helical wake, which is skewed in forware flight, are easily generated in a prescribed wake type of analysis given the governing parameters which can be iterated on if desired. If analytical, realistic distorted wake geometries require more complex and operationally expensive computer analyses. Appropriate experimental wake data is certainly most desirable, but is not currently available for most rotor configurations and flight conditions. It has been established that the requirement for distortions from the classical type wake geometry is dependent on the rotorcraft configuration, flight condition, parameter of interest and accuracy required. For example, an undistorted wake geometry is generally sufficiently accurate for integrated performance calculations (thrust, torque, etc.) for conventional rotorcraft operating in high speed flight. However, low speed flight conditions wake distortions are very significant.

Complete generality regarding the specification of the wake geometry is provided in the computer program. This was accomplished by requiring that the wake coordinates for the wake segment end points be stored on tape for computational purposes in a prescribed format, thus no requirement was made as to how these coordinates are obtained. This facilitates the adaption of improved wake models to the program as they become available. For this program at the present time several options are available for wake geometry. The following three types of wake models are presently available: (1) A classical undistorted wake model option is available internally, which computes wake coordinates and stores them on tape, (2) an analytical wake model (undistorted or distorted wake) can be obtained from a separate wake geometry program which can be run linked to this program, and (3) a provision is available for a classical wake with a tip filament overwrite using available experimental data.

Undistorted Wake Model - In its simplest form, the wake can be assumed
to be a classical undistorted skewed helical sheet of vorticity defined
from momentum considerations (hereafter referred to as the undistorted wake).
A sample undistorted wake representation is shown in Fig. 4. The coordinates
of the undistorted wake representation are obtained from the rotor advance
ratio, , thrust coefficient, C_T, and angle of attack relative to the tip
path plane, α_{TPP}. For example, the top view of the tip vortex filaments
is obtained directly from the helicoidal path of the blade tip as it translates
at the velocity $V_{cos} \alpha_{TPP}$ and rotates at the velocity R. The side view is
dependent on the wake skew angle (angle between normal to the rotor disc
and wake boundary), which is normally defined from momentum considerations.

Subroutine CLASWK is used to provide a classical undistorted wake
geometry. The axial transport velocity of all wake segment end points is
equal to a constant which is an input item. For example, the momentum
induced velocity has normally been used for this value. The surface boundary
of the resulting wake model is therefore a skewed cylinder in shape. Each
wake filament thus forms a skewed helix.

Distorted Wake Model - A distorted wake model may be incorporated
in the analysis via tape input. A rotor wake geometry analysis, such as
that developed at UARL and described in References 1 and 2, can be used
to generate wake coordinates on tape for use in the rotor inflow analysis.

In addition to tape input, a provision is available in the inflow
program for overwriting the coordinates of the undistorted tip filaments,
generated internally, with tip vortex coordinates determined from another
source (experimental or analytical). This option can be used to more
accurately model the important tip vortex geometry.

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TOP VIEW
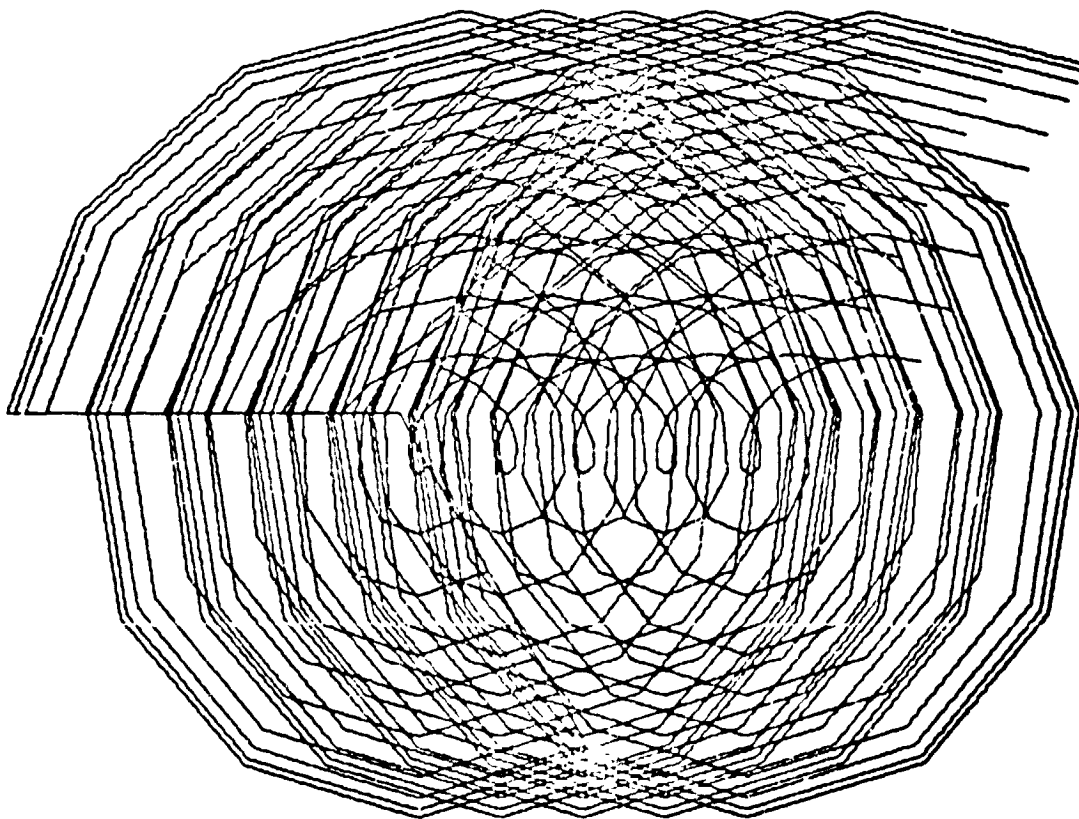
SIDE VIEW

Figure 4.   Computer Wake Representation -
Undistorted Wake

Wake Coordinate System - A Cartesian coordinate system is used in the program to define the wake geometry. The coordinate system is defined as follows:

1) Coordinates are nondimensionalized by the rotor radius.
2) Origin lies at the center of the rotor hub.
3) The x-y plane is parallel to the rotor tip path plane.
4) The coordinate system is a right handed system with z positive upwards.
5) The coordinate system is aligned such that positive x is always in the downstream direction and zero azimuth lies on the positive x axis.

Circulation and Induced Velocity Solution

Following the formulation of the wake geometry representation in the program, the geometric relations between the wake and the blades are calculated, and the equations for the blade circulations and induced velocities are applied. The Kutta-Joukowski law and the Biot-Savart law are the basic relations used to obtain a closed form solution for these parameters. The Kutta-Joukowski law relates the blade circulation and induced velocity distributions. The Biot-Savart law relates the blade induced velocity distribution to the wake circulations and wake geometry. The term "geometric coefficient" is used to describe the influence coefficients in the latter relation, which are functions only of the wake geometry. Several assumptions, mentioned above, for the airfoil lift characteristics, velocity components, and inflow angles were included in the establishment of the circulation matrix in order to linearize the solution. The solution procedure consists mainly of (1) determination of the geometric coefficients, (2) establishment of the circulation matrix, (3) solution of the circulation matrix by a modified Gauss-Seidel iteration technique, (4) solution of the induced velocity distribution (inflow) using the results of the circulation solution, and (5) harmonic analysis of the inflow solution and calculation of associated parameters.

In order to summarize the technical approach and indicate where assumptions are made, the primary equations contained in the circulation and inflow solution and a brief derivation thereof are presented below.

In order to relate to the program input-output symbols and to describe some of the symbols generated within the program, program symbol notation is used in the following equations.

The blade circulation at any blade segment I, for any azimuthal position J, is; from the Kutta-Joukowski relation,

$$CIRC(I,J) = C(I) \cdot U(I,J) \cdot CL(I,J)/2 \tag{1}$$

where   CIRC(I,J) = local blade element circulation, ft^2/sec

C(I)   = local blade element chord, ft

U(I,J)   = local blade element resultant velocity, fps

CL(I,J)   = local blade element lift coefficient

The local blade element resultant velocity U(I,J) can be expressed as

$$U(I,J)^2 = \left[UT(I,J) + UTI(I,J) \right]^2 + \left[W1(I,J) + W(I,J) \right]^2 \tag{2}$$

where $UT(I,J) = OMGR \cdot (RS(I) + MU \cdot SIN(PSI))$ \hfill (3)

and   OMGR   = Rotor tip speed, fps

MU   = Rotor advance ratio

RS(I)   = Rotor blade segment radial position (nondimensionalized by R)

UTI(I,J)   = Induced tangential velocity, fps

W(I,J)   = Induced inflow velocity, fps

and with small angle assumptions

W1(I,J)   = Noninduced inflow velocity (flapping, pitching, aeroelastics, etc.), fps.

For helicopter rotors, UTI(I,J) may be neglected. Also since W(I,J) and W1(I,J) are small in the important blade tip region relative to the rotational velocity, it is assumed that

$$U(I,J) = UT(I,J) \tag{4}$$

so that a linear closed form solution can be obtained. Also, in order to linearize the solution, the lift coefficient is expressed as

$$CL(I,J) = AT(I,J) \cdot ALPHAE(I,J) \tag{5}$$

where $AT(I,J)$ = local blade element lift curve slope

ALPHAE(I,J) = local blade element angle of attack

In stall, the maximum lift coefficient is limited in the program to CLMAX(I,J) which is determined from input values of angle of attack values (ALMAX(I,J) beyond which stall is assumed. The angle of attack is, for small angle assumptions and consistent with the above assumptions,

$$ALPHAE(I,J) = \left[W1(I,J) + W(I,J) \right] / UT(I,J) \tag{6}$$

Substituting Equations (4) through (6) into Equation (1), the circulation equation becomes,

$$CIRC(I,J) = C(I) \cdot AT(I,J) \cdot \left[W1(I,J) + W(I,J) \right] / 2 \tag{7}$$

Since there are MSIZE unknowns,

where   MSIZE = (ITOT +1) $\cdot$ JTOT and ITOT and JTOT are the total number of blade segments and azimuth positions,
there are MSIZE equations of the form of Equation (7). This set of MSIZE equations can be written in matrix notation as:

$$CIRC(I,J) = \left[C(I) \cdot AT(I,J) \cdot \left\{ W1(I,J) + W(I,J) \right\} \right] \tag{8}$$

The axial induced velocity in Equations (7) and (8) is expressed, using the Biot-Savart law, as a function of the trailing wake filaments and circulation strengths. The axial velocity induced by a given wake segment (subscript M) of filament K at a given blade segment (I,J) is expressed in terms of the Biot-Savart law as

$$W(K,M) = CIRCT(K,M)/4\pi R \cdot GC(K,M) \tag{9}$$

where   CIRCT(K,M) = circulation strength of the Mth segment of the Kth filament, ft^2/sec

GC(K,M)   = geometric influence coefficient from the Biot-Savart law

The geometric coefficient, GC, is a function only of the prescribed wake coordinates $(X(K,M), Y(K,M), Z(K,M))$. The lengthy expressions for GC may be obtained from the program listing included herein (Subroutine Jack). Since the circulation distribution is assumed to be periodic in time for the forward flight condition, each wake filament has a periodic circulation strength distribution along its length. The total axial induced velocity due to contributions of all trailing circulations for all of the filaments at the blade point (I,J) is the sum of Equation (9) evaluated for all segments in the wake. The resultant expression from Equation (9) becomes

$$W(I,J) = \frac{1}{4\pi R} \sum_{K}^{KLIM} \sum_{M}^{MLIM} CIRCT(K,M) \cdot GC(K,M) \tag{10}$$

where KLIM is the total number of trailing filaments, and MLIM is the total number of segment end points for each filament.

However since the circulations are periodic in M this relationship can be expressed by combining elements with like circulations,

$$W(I,J) = \frac{1}{4\pi R} \sum_{K}^{KLIM} \sum_{MM}^{JTOT} CIRCT(K,MM) \cdot GCTROW(K,MM) \tag{11}$$

where

$$GCTROW(K,MM) = \sum_{(M=MM)}^{MLIM} GC(K,M)$$

MM combines all elements of a vortex filament shed from a blade at the same blade azimuth position, and thus combines elements with like circulations. The total induced velocity due to all bound circulations of the rotor can be expressed as,

$$WB(I,J) = \frac{1}{4\pi R} \sum_{IB}^{B} \sum_{I}^{ITOT} \sum_{MM}^{JTOT} CIRC(I,MM) \cdot GCB(I,MM) \tag{12}$$

where   GCB(I,MM) = geometric coefficient due to bound circulation (using Biot-Savart law)

     WB(I,J)   = induced axial velocity due to bound circulation

     IB   = number of blades

     ITOT   = number of bound segments per blade

In order to express the total axial induced velocity due to all of the trailing circulations in terms of the bound circulation, the circulation strength of each trailing filament segment may be expressed as the difference between the bound circulation of the two blade segments adjacent to its point of origin at the blade at the time of generation. Thus,

$$CIRCT(K,MM) = CIRC(K,MM) - CIRC(K-1,MM) \tag{13}$$

Substituting Equation (12) and Equation (13) in Equation (11), the total axial induced velocity becomes

$$W(I,J) + \frac{1}{4\pi R} \sum_{K}^{KLIM} \sum_{MM}^{JTOT} CIRCT(K,MM) \cdot GCTROW(K,MM)$$

$$+ \frac{1}{4\pi R} \sum_{1B}^{B} \sum_{I}^{ITOT} \sum_{MM}^{JTOT} CIRC(I,M) \cdot GCB(I,MM) \tag{14}$$

Rearranging Equation (14) to combine like circulations leads to

$$W(I,J) = \frac{1}{4\pi R} \sum_{IB}^{B} \sum_{II}^{ITOT} \sum_{MM}^{JTOT} CIRC(II,MM) \cdot GCDIM(II,MM) \tag{15}$$

where $GCDIM(II,MM) = GCTROW(II+1,MM) - GCTROW(II,MM)$

$$+ GCT(II,MM)$$

Substitution of Equation (15) in Equation (8) results in a matrix equation in which the only unknowns are the bound circulation, $CIRC(I,J)$

$$\left[CIRC \right] = \left[CONST \right] + \left\{ GCMAT \right\} \left[CIRC \right] \tag{16}$$

where   GCMAT = final matrix influence coefficients

CONST = matrix constants which are only functions of the known
input quantities.

Solving for CIRC:
$$\left[CIRC \right] = \left[CONST \right] \left\{ 1-GCMAT \right\}^{-1} \tag{17}$$

A Gauss-Seidal numerical iteration technique for evaluating this circulation matrix is included in the computer program. Following the circulation solution, the induced velocity distribution is obtained from Equation (8).

COMPUTER SYSTEM INFORMATION AND PROGRAM STRUCTURE

The UARL Prescribed Rotor Wake Inflow Analysis Program (Deck F389) is programmed in Fortran V computer language for use on the UNIVAC 1110 high-speed digital computer. The program has been converted for use on IBM 370 and 360 computers.

The structure of the program consists of an initial routine (F389), a major subroutine (JACK), and a series of minor subroutines. The symbolic names for the program subroutines are listed below. A brief description of each of the subroutines is presented in Appendix I. A diagram of the subroutine calling sequence is presented in Figure 5.

PROGRAM SUBROUTINES

AERPAR	ANALYS	BLAGE	BLDXYZ
CIRPRT	CLASWK	DATAIN	DISWAK
FLAPIT	F389	HARM	INDAT
INTERP	INTPO	INTPOE	INTVEL
JACK	LINKUP	LOADER	MILSOP
MLSOP2	⊢COORD	PLOTIT	PRINIT
PRINT2	REW	RREC	SKPFIL
TIPWAK	TTRAP	UAERO	WEF
WREC			

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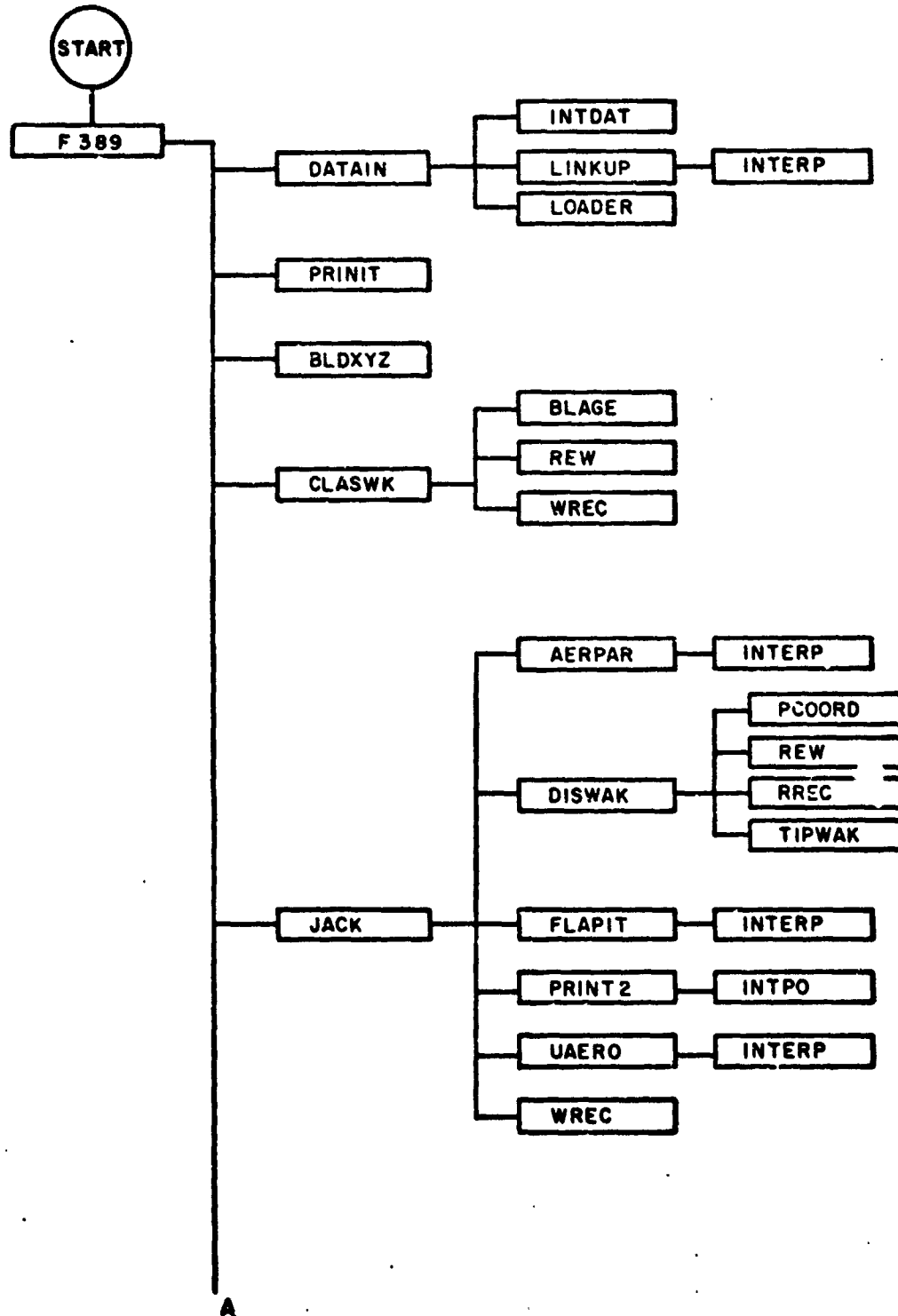
Figure 5. Subroutine Calling Sequence Diagram
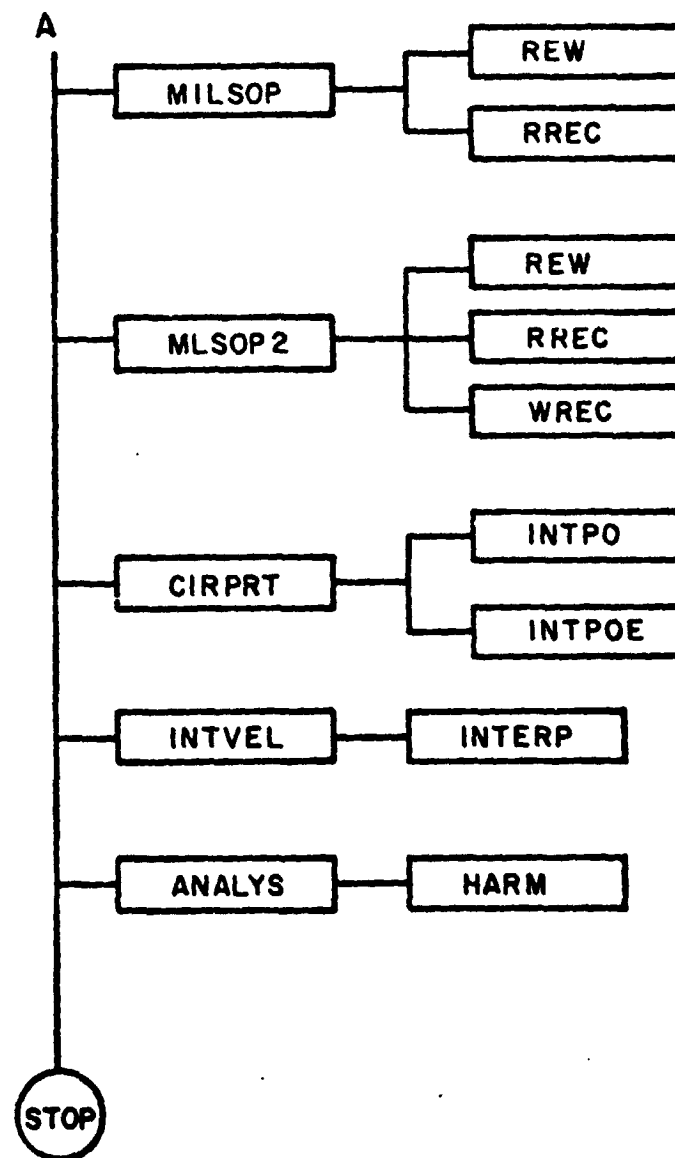
Figure 5. Concluded

SUBROUTINE CLASWK

This subroutine computes a classical undistorted wake. The wake
is hub referenced and parallel to the tip path plane. After the wake
has been generated it is written on tape. If blade lagging is desired,
Subroutine BLAGE is called. Subroutine BEW, WEF and WREC are also called
from this subroutine.

SUBROUTINE DATAIN

This subroutine controls input of basic variable data and computes
control associated parameters and constants. These parameters and constants
are stored in named common blocks to be used throughout the whole program.
It calls subroutine LOADER.

SUBROUTINE DISWAK

This subroutine controls the input wake geometry from tape and the
associated wake print option. It is called for each rotor position.
The wake geometry is read from tape by a tape reading subroutine SREC.
The tip wake overwrite option is used in this subroutine. The following
subroutines are called from this program: PCOORD, REW, SKPFIL, TIPWAK.

SUBROUTINE FLAPIT

This subroutine computes or reads in by cards the blade element
noninduced axial velocity component (W1). Rigid blade equations are used if
W1 is internally computed. W1 can be input by cards via this subroutine.

SUBROUTINE F389

This is the main program and controls the flow of the program. The
following subroutines are called in F389: ANALYS, BLDXYZ, CIRPRT, CLASWK,
DATAIN, INTVEL, ACK, MILSOP, MILSOP2, PRINIT, TTRAP.

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SUBROUTINE HARM

This subroutine harmonically analyzes data and computes the harmonic coefficients for a positive Fourier series.

SUBROUTINE INDAT

This subroutine is used when running linked with another program. It loads into the variable input array a set of standard input items.

SUBROUTINE INTERP

This subroutine is a linear interpolation subroutine. It is used throughout the program wherever linear interpolation is required.

SUBROUTINE INTPO

This is a print option subroutine which used fixed point output format. It is used for printing out variables as a function of blade aximuth and blade radial position.

SUBROUTINE INTPOE

This is a print option subroutine which uses an exponential output format. It is also used to output information as a function of blade azimuth position and blade radial station.

SUBROUTINE INTVEL

This subroutine is used to control the interpolation of inflow velocities and the output of these velocities. This subroutine calls subroutine INTERP.

SUBROUTINE JACK

This subroutine is the major computational subroutine. It computes the geometric influence coefficients of each wake element at each blade radial station and azimuth position. Geometric coefficients for both bound and trailing vortex elements are computed in this subroutine. It calls subroutines AERPAR, DISWAK, FLAPIT, PRINT2, UAERO, UREC.

SUBROUTINE LINKUP

This subroutine links another program to this program and allows transferal of data via drum.

SUBROUTINE LOADER

This subroutine reads variable input data from cards with a specified format.

SUBROUTINE MILSOP

This subroutine solves for circulations using a Gauss Seidel iteration technique. If the circulation matrix is "small" (i.e., can be stored in the computer), the geometric influence coefficients are read from drum into core and stored in matrix form. The above technique is then applied to determine the circulation solutions. If the circulation matrix is large Subroutine MLSOP2 is used. Incorporated into the iteration technique is a check on maximum circulation as determined from stall considerations. If any guess in the iteration exceeds the maximum circulation, this guess is reset to the maximum circulation and iteration continues. It calls Subroutines REW, and RREC.

SUBROUTINE MILSOP2

This subroutine solves for circulations using the Gauss Seidel technique when the matrix is "large" (i.e., matrix is too large to store in the computer). The only difference between this subroutine and the previous subroutine MILSOP is that the matrix is manipulated on drum during the iteration sequence (matrix is not stored in core). It calls subroutines REW, RREC, and WREC.

SUBROUTINE PCOORD

This subroutine is used to print wake geometry coordinates.

SUBROUTINE PRINIT

This subroutine prints the basic variable input data in a special output format which is compatible with the loader input requirements. It also prints the variable's location in the array. name description, units and value.

SUBROUTINE REW

This subroutine rewinds a desired tape or drum unit when called.

SUBROUTINE RREC

This subroutine reads a record of specified length from drum or tape.

SUBROUTINE SKPFIL

This subroutine skips a file on tape when called.

SUBROUTINE TIPWAK

This subroutine will read tip wake filament geometry from cards when called, and overwrites the classical wake tip filament geometry.

SUBROUTINE TTRAP

This is a time trap subroutine which computes the time required to complete various portions of the program.

SUBROUTINE UAERO

This subroutine computes sectional airfoil characteristics from information obtained in card form from another program. It uses subroutine INTERP.

SUBROUTINE WEF

This subroutine will write an "end of file" on either drum or tape when called.

SUBROUTINE WREC

This subroutine is used for drum writing purposes. It writes a record of specified length on either drum or tape.

Modes of Operation (Linked vs. Independent)

The rotor inflow program (Deck F389) can be used in either of two modes of operation -- linked or independent.

For the linked mode of operation, the inflow program is coupled (linked) directly to the blade response program, Y141 (see Fig. 1) and the two programs are run as one. That is the blade response program provides the necessary input to the inflow program, and the inflow program then computes and transmits the inflow solutions to the blade response program. In this manner of operation, unless overwritten with separate input for Deck F389, all of the input items necessary for execution of the inflow program are transmitted from the blade response program or preset internally in the inflow program. The flight condition, rotor design, rotor pitch control, blade response, and airfoil data parameters are input to or computed in the blade response program (Y141) and transmitted internally to the inflow program (F389). Most of the rotor and wake model parameters and option controls are preset internally in the inflow program. This relieves the requirement for input to the inflow program for linked operation other than two control cards to be described. However, caution should be exercised by reviewing the input instructions to insure that the transmitted and preset values conform with the requirements for the specific rotor configuration and operating condition of interest. Any of the transmitted or preset values may be overwritten, if desired, with the appropriate selection of input items via a secondary LOADER input provision to be discussed. Generally, it is necessary to overwrite at least a few items. For some cases selection of certain items (e.g., inflow stations, wake roll-up, core radius, etc.) may be critical for accurate solutions. Thus it is recommended that the user become familiar with all of the inflow program input items for effective use of the program.

The second mode of operation of the inflow program is the independent (stand alone) mode, whereby the program functions without being coupled to the blade response program. For this mode of operation, all of the input items must be input via cards.

DESCRIPTION OF PROGRAM INPUT

Summary of Input Parameters

The input required for the rotor inflow program are summarized below by grouping the input parameters into descriptive categories.

Flight Condition Parameters:	Flight velocity, rotor tip speed, rotor shaft angle, speed of sound
Rotor Design Parameters:	Number of blades, flapping hinge, offset ratio, rotor radius, blade chord, blade twist, blade precone (for hingeless rotor), tip anhedral
Rotor Pitch Control Parameters:	Collective pitch, cyclic pitch
Blade Response Parameters:	Coning (articulated rotor), flapping angles, lag angle, blade bending and torsional flexibility (optional)
Rotor Model Parameters:	Radial stations, azimuth increment
Wake Model Parameters:	Azimuth increment, number of wake revolutions, wake transport velocity, vortex core radius, number of vortex filaments to rollup in tip vortex, tip vortex rollup azimuth, inboard wake truncation azimuth, tip vortex coordinates (optional)
Airfoil Data:	Lift curve slopes, stall angles of attack, angles of attack for zero lift (all vs. Mach number)
Option Controls:	Print, punch, link, and input controls

Although the number of input parameters appears large, provisions have been incorporated in the program to facilitate the input setup by:

(1) omitting input for unnecessary parameters for specific cases,

(2) internally prescribing input quantities when operating in the linked mode, and

(3) avoiding input repetition for multiple cases.

Sequence of Input

The input sequence for the computer card input is:

1. Basic Variable Input Data (LOADER FORMAT)

2. Multiple Case Control (1 Card)

3. Secondary Changes in Variable Data, LOADER FORMAT, (Optional)

4. Multiple Case Control (1 Card)

5. Sectional Airfoil Characteristics Input (Optional)

6. W1 Input (Optional)

7. Tip Vortex Coordinate Overwrite Input (Optional)

For runs with multiple cases, the input sequence for cases following the first case is identical except that repetition of data in the Basic Variable Data is not required.*

A detailed description of the input items follows below. A sample listing of the input data in computer card format and computer printout format is presented in a later section of this report.

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* A computer case is referred to as the inflow solution for one combination of rotor design, operating condition, and wake geometry. A computer run is referred to as the inflow solution for one case or multiple cases submitted to the computer at one time.

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
1	517	V	Flight velocity, kt. This item is used in computations involving various blade element aerodynamic quantities.
2	1	OMGR	Rotor tip speed, fps. Product of the rotor rotational velocity (rad/sec) and the rotor radius (ft).
3	466	SOUND	Speed of sound, fps. This item is used in calculation of local blade element Mach number.
4		DPSI	Azimuth increment, deg. This item defines the computational azimuth increment of a blade over one revolution. It also is used to divide the trailing wake filaments into elements and to define the azimuth interval of the circulation and inflow solution. 360/(B·DPSI) must be an integer. DPSI must be equal to or greater than 10 deg. 15 deg is normally used for 2, 3, 4, 6, or 8 blades, although 30 deg is used when computer cost is more of a concern than increased accuracy. (Linked Version: prescribed as 15 deg except for five blades (12 deg) and seven blades (17.143 deg). Transferred from Deck Y141).
5	2	R	Rotor radius, ft.
6	130	B	Number of blades
7-21		C	Blade chord for each segment in the inflow solution, ft. Maximum of 15. Ordered from the innermost of the outermost segment. (Linked Version: interpolated internally at radial stations for inflow solution(locations 24-38) from input chord lengths in locations 150-164 of Deck Y141).

* Linked Version. Locations in Deck Y141 for automatic transfer of input to appropriate locations in F389 module.

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
22	3	E	Blade flapping hinge offset ratio. Offset nondimensionalized by the rotor radius, R. Used to obtain blade segment orientation.
23		STNS	Number of blade segments used for the inflow solution. A maximum of 15 is allowed. Normally, 9 segments are used. (Linked Version: prescribed internally as 9.)
24-38		RS	Radial coordinates of blade segment centers (blade stations) for the inflow solution nondimensionalized by the rotor radius, R. These coordinates are used to define the representative locations of the blade segments for which the aerodynamic parameters are calculated and the inflow solutions are obtained. In addition, the boundaries of the blade segments, which designate the origins of the trailing vortex filaments, are calculated from these segment center locations. The innermost segment center is normally selected so as to position the corresponding innermost segment boundary at the blade root cutout position (inner aerodynamic boundary of blade). The maximum number of blade segments is 15. Careful selection of the RS values must be made to insure that the radial position of each segment boundary between adjacent segments is identical (i.e., segments do not overlap). The innermost value must be the first value of RS. Careful selection of the segment center locations is necessary to avoid introducing numerical inaccuracies associated with the use of finite vortex filaments. Smaller segments in regions of large bound circulation gradients (e.g., at the blade tip) are required. Segment lengths less than 0.02R should normally be avoided. See Fig. 3 and the section, Special Input and Operating Instructions for a typical segment distribution.

LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
			(Linked Version: prescribed internally as 0.225, 0.375, 0.525, 0.65, 0.75, 0.85, 0.925, 0.965, 0.99. First and/or second segments are internally adjusted to conform to root cutout as defined by Location 133 in Deck Y141.)
	39	STNEW	Number of blade segments for the interpolation of the inflow solution and harmonic analysis of the inflow. If this it . is zero the inflow at the solution segment centers (RS) are used for the harmonic analysis. If the sectional airfoil data option (Location 207) is used these are the stations for which the sectional airfoil data are input. A maximum of 25 is allowed. (Linked Version: Transferred from Deck Y141 as 15.)
	40-64	RSNEW	Radial coordinates of blade segment centers of interpolation calculations (nondimensionalized by R). These segments are not used in the circulation and inflow calculations. They are used only to interpolate the inflow solutions at the original segments (RS) to these new radial locations. Normally, RSNEW values are not input and the original RS segments are used throughout the computation. A limit of 25 RSNEW values exists in the program. The innermost value must be the first value in RSNEW. (Linked Version: calculated in Deck Y141 from information in Locations 5-19 and transferred.)

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
65		VIMOM	Wake transport velocity, fps. Positive upflow. This velocity is only used if the undistorted wake model is to be internally generated in the program. It is used to define the transport velocity, normal to the rotor disc. Normally, the momentum inflow velocity is used as defined by the following equations:

$$VIMOM = -\frac{1}{2}\frac{C_T \Omega R}{\sqrt{\mu^2 + \lambda^2}}$$

where R, C_T, , and are the tip speed, thrust coefficient, advance ratio and inflow ratio as conventionally defined in Ref. 7. (Linked Version: calculated in Deck Y141 and transferred.)

66	507	ALPHAS	Rotor shaft angle, deg. Positive shaft angle corresponds to a nose-up tilt of the aircraft. Referenced to the forward flight velocity.
67	515	THET75	Blade collective pitch at the 0.75R station, deg. This item is used in conjunction with THETA1 and DTHETA to calculate the blade pitch distribution.
68	136	THETA1	Blade linear twist rate, deg. This input item is used to calculate the blade built-in pitch distribution for linearly twisted blades, and is normally negative to indicate decreased built-in pitch angles at the blade tip. The blade pitch, THETA, at each station, I, is calculated from the following equation:

$$THETA(I) = THET75 + THETA1 \; (RS(I)-0.75)+DTHETA(I)$$

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
69-83		DTHETA	Increment of blade pitch angle at each inflow solution blade station (RS), deg. For a nonlinear twisted blade, this item is used in place of or in conjunction with THETA1 to define the built-in pitch angle at each station, I, due to blade twist (see above equation). The value for the innermost station must be the first value of DTHETA. (Linked Version: interpolated internally at radial stations for inflow solution (Locs. 24-38) from information in Locations 165 to 179 in Deck Y141.)
84	513	A1SP	The first cosine harmonic coefficient of cyclic pitch, deg. Shaft axis system. Based on negative Fourier series.
85	514	B1SP	The first sine harmonic coefficient of cyclic pitch, deg. Shaft axis system. Based on negative Fourier series.
86		DELPSI	Blade phase angle, deg. This item can be used to position the rotor in any desired starting location relative to the zero azimuth position. It is positive in the direction of rotation. Normally not input and blade 1 of the rotor is assumed to lie at zero deg for rotor position 1. (Linked Version: prescribed internally as 0.0).
87		DELTA	Blade lag-angle, deg. Positive opposite to the direction of rotation. A constant lag angle is assumed. (Linked Version: transferred from Deck Y141 as the mean lag angle computed therein.)
88-98			Not used.
99			Multiple case control card, see section entitled, Multiple Case Control and Secondary Variable Input. (Linked Version: multiple case control cards must be provided.)

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LOCATIONS		PROGRAM	
		Symbol	
Deck	Deck	in	
F389	Yl41*	Deck F389	DESCRIPTION OF INPUT ITEM

100-120		CURVE	Airfoil lift curve slope vs. Mach number table, C_l/rad. The first location is the number of pairs of data. The data pairs follow (Mach No., C_l/rad) with a minimum of 2. The data pairs are ordered in Mach number, lowest Mach number pair first. An interpolation routine is provided in the program which linearly interpolates on Mach number. Care must be taken to cover the Mach number range involved. An initial negative Mach number is required for the reverse flow region. These input values are used in the linearized circulation solution. (Linked Version: not used in linked mode. This information is provided by lift curve slopes at each segment and azimuth as transferred from Deck Yl41. See section on Sectional Airfoil Characteristics Input.)
121-141		ACURVE	Angle of maximum lift coefficient vs. Mach number table. Uses the same input format as CURVE. These input values are used to define the stall limits in the linearized circulation solution. (Linked Version: not used in linked mode. This information is provided by angles of maximum lift coefficient at each segment and azimuth as transferred from Deck Yl41. See section on Sectional Airfoil Characteristics Input.)
142-162		AOCURV	Angle of zero lift vs. Mach number table, deg. For blades with cambered airfoil sections. Uses the same input format as CURVE. These input values are used in the linearized circulation solution. (Linked Version: not used in linked mode. This information is provided by angles of zero lift at each section and azimuth as transferred from Deck Yl41. See section on Sectional Airfoil Characteristics Input.)

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
			and a 4.0 indicates a wake model from the tape output of another program. (Linked Version: prescribed internally as 1.0.)
187		RUN	Run number for wake geometry location on tape. A 1.0 is used for TYWAKE=1., 2., and 3. (Linked Version: prescribed internally as 1.0.)
188		TSTEP	Time step in tape file to start using wake geometry. Used only when TYWAKE = 4. (Linked Version: prescribed internally as 0.0.)
189		REV	Number of wake revolutions. Selection of this item is a compromise between accuracy and computer cost. The following values are typical: for hover (advance ratio, μ = 0) use at least 8 revs; for 0 − 0.05 use 6 revs; for 0.05 − 0.1 use 4 revs; for 0.1 − 0.15 use 3 revs; for $\mu \geq 0.15$ use 2 revs. (Linked Version: prescribed internally as 5 0. Caution − it may be desirable to overwrite this value as described above.)
190		ROLLUP	The number of filaments to rollup in the tip vortex (at rollup angle TRUNC). If rollup is not desired, such as for a classical wake, use 0.0 or 1.0. If rollup is desired, this value should be the number of tip vortex filaments outboard of the radial station at which the peak circulation occurs. This value is assumed constant (not varying with azimuth position), and thus a representative value must be selected. Since this value is not known a priori, it must be estimated, and if necessary iterated on. In hover the peak circulation normally occurs between 0.9 and 0.96R. In high speed forward flight it normally occurs between 0.7 and 0.85R. (Linked Version: prescribed internally as 5.0. Caution − it may be necessary to overwrite this value as described above.)

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
191		ANDTIP	Option indicator for anhedral tip design. A 0.0 indicates no droop, a 1.0 indicates a linear droop computed internally using DROOP, and a 2.0 indicates input droop coordinates (see Loc. 195). (Linked Version: prescribed internally as 0.0.)
192		DROOP	Linear droop angle for anhedral tip, positive down, deg. (Linked Version: prescribed internally as 0.0.)
193		RBEND	Radial location for the start of the droop section, nondimensionalized by R. It must be positioned such that there are no more than 5 inflow stations outboard of this location. (Linked Version: prescribed internally as 0.0.)
194		RATIOV	Ratio of the tip filament displacement velocity to VIMOM of the wake. If not input or a 0.0 is input the value is automatically set equal to 1.0. (Linked Version: prescribed internally as 0.0).
195-199		ZANDTP	Axial coordinates of the drooped stations nondimensionalized by R. Referenced to unconed, undrooped blade. Dihedral: positive; Anhedral: negative. Maximum of 5 are allowed. This is used only if ANDTIP is set to 2.0. (Linked Version: prescribed internally as 0.0.)
200		TRUNC	Angle of rollup of the tip vortex filaments with respect to the blade, deg. Tip vortex filaments beyond this wake azimuth angle are all assigned coordinates equivalent to the outermost tip filament, thereby simulating the rollup of the tip vorticity into a concentrated tip vortex. TRUNC/DPSI must be an integer. A typical value of TRUNC is 30. If no rollup is desired, set TRUNC = 0.0. (Linked Version: set equal to DPSI (Location 4). Transferred from Deck Y141).

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LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
201		TRUNCI	Truncation angle of vortex sheet filaments with respect to the blade, deg. Normally, TRUNCI = 0.0 which suppresses the truncation feature. If a truncation angle is desired, TRUNCI = wake azimuth angle for truncation. (Linked Version: prescribed internally as 0.0.)
202		RCORE	Tip vortex filament core radius nondimensionalized by the rotor radius. Generally a value of approximately 0.1 of the blade chord is used. Caution - RCORE must not exceed one-half of the length of the outer blade segment. (Linked Version: calculated internally as one-tenth the tip chord.)
203		RCOREI	Vortex filament core radius for filaments representing the inboard vortex sheet, nondimensionalized by the rotor radius. Caution - RCOREI must not exceed one-half the length of the smallest blade segment. (Linked Version: calculated internally as one-tenth the tip chord.)
204			Not used.
205		TOL	Tolerance control for the matrix solution of circulations. Normally, set TOL = 0.0 and a tolerance of 0.0005 will be used (tolerance = allowable difference in summation of circulation solutions between last and previous iteration divided by summation for last iteration). Thus 0.0005 represents a 0.05% accuracy of convergence of the solution summation. If a tolerance value other than 0.0005 is desired, set TOL equal to the desired value. (Linked Version: prescribed internally as 0.0.)

LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
206		W1OPT	Option indicator for W1 input. If a value of 0.0 is input W1 is computed from rigid blade equations using flapping harmonics and blade control parameters. A value of 1.0 indicates that W1's will be read in via cards. See section entitled, Noninduced Axial Velocity Component Input, W1. (Linked Version: prescribed internally as 1.0. Input cards are replaced by data transferred from Deck Y141).
207		WOPT	Option for sectional airfoil data input via cards. A 0.0. indicates no unsteady aerodynamics. A value of 1.0 indicates that sectional airfoil data input will be read from cards. See section entitled, Sectional Airfoil Characteristics Input. (Linked Version: prescribed internally as 1.0. Input cards are replaced by data transferred from Deck Y141.)
208		OPTPO	Geometric coefficients print option. A 0.0. indicates no print; a 1.0 calls for the print option. (Linked Version: prescribed internally as 0.0.)
209		PRINT	The matrix solution print option. A 0.0 indicates no printout; a 1.0 calls for printout of the matrix coefficients and solution at each iteration, and a 2.0 prints only the solutions at each iteration. (Linked Version: prescribed internally as 0.0.)
210		PUNCH	Card punch option for induced velocities. A 0.0 indicates no punch cards, a 1.0 requests harmonics of induced velocity, a 2.0 requests induced velocities at each point in the rotor disc, and a 3.0 requests both harmonics and point values. (Linked Version: prescribed internally as 0.0.)
211		CPOPT	Wake coordinate print option. A 0.0 indicates no print, a 1.0 calls for a printout of the wake coordinates. (Linked Version: prescribed internally as 0.0.)

LOCATIONS		PROGRAM	
Deck F389	Deck Y141*	Symbol in Deck F389	DESCRIPTION OF INPUT ITEM
212		CROPT	Print option for wake-element point combinations within the core radius. A 0.0 input indicates no printout, while a 1.0 calls for the printout. (Linked Version: prescribed internally as 0.0.)
213		CPUNCH	Option for punched cards of the rotor circulation solutions. A 0.0 indicates no punch, while a 1.0 calls for punched card output. (Linked Version: prescribed internally as 0.0.)
214-219			Not used.
220		OPLINK	Option for running linked to other aeroelastic type programs. A 0.0 indicates normal unlinked operation. A 1.0 indicates normal linked operation, and the program will automatically adjust for root cutout. If the root cutout is inboard of the second inflow station, OPLINK should be set equal to 2.0. This will bypass the root cutout adjustment when running linked, but it also implies that the required inflow stations will be input via the secondary loader input. (Linked Version: prescribed internally as 1.0.)
221		DEBUGP	Option for intermediate printout, a 0.0 indicates no printout, a 1.0 requests printout. (Linked Version: prescribed internally as 0.0.)

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Card No.	Column	Program Symbol	Description of Input Item
	13-24,		Starting at the innermost station, 5 to a card for as many stations as are required.
	25-36,		
	37-48,		
	49-60.		
3		TAB	
•		•	
•		•	
•		•	
N		TAB	
N+1	1-12	TAB	Angle of zero lift, starting at the innermost station, 5 to a card for as many stations as are required (deg.).
	13-24,		
	25-36,		
	37-48,		
	49-60		
N+2		TAB	
•		•	
•		•	
•		•	
N+M		TAB	
N+M+1	1-12,	TAB	Slope of the lift curve, starting at innermost station, 5 to a card for as stations as are required (C_1/rad.).
	13-24,		
	25-36,		
	37-48,		
	49-60		
N+M+2		TAB	
•		•	
•		•	
•		•	
N+		TAB	

Repeat the sequence starting with card 1 for the next blade position, until data for all rotor azimuth positions have been input.

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Noninduced Axial Velocity Component Input, W1

The noninduced axial velocity component, W1, may be either calculated internally in the program or read in via cards. The option control in the basic variable input is W1OPT. If calculated internally, blade flexibility is neglected and rigid, articulated blade equations are used to include the influence of rotor attitude, pitch angle and flapping motions, W1 values for each point in the rotor disc may be input on cards to include blade flexibility effects. This is particularly useful when the W1 values are calculated in another computer program. Appropriate values for articulated or nonarticulated rotors may be used. When including flexibility effects, the total noninduced axial velocity component, W1, consists of axial velocity components due to both torsional and bending flexibility in addition to the rigid blade axial velocity. The W1 velocity is defined to be positive for upflow. The W1 values are input for the RSNEW stations and linearly interpolated in the program to the inflow stations, RS. The required input format is presented below.

The data is input six items to a card using a Fortran 6E12.5 format. There is a set of cards for each radial interpolated inflow solution station (RSNEW). The sets are ordered from the innermost to the outermost station. Each set of cards consists of the W1 values at all azimuthal positions for a given radial station. These values must start at the first actual blade azimuthal position (J = 1), and are ordered azimuthally in the direction of rotation; therefore, care must be taken when blade phasing is used to insure the correct order of input. Starting with the first set, a card is filled with 6 items, then a new card is started; if needed. This is continued until all azimuthal positions for a given set are complete. For the next station this process is repeated. There are no title cards or blank cards used. For example, a case with 15 azimuthal positions (DPSI = 24 deg) and 9 blade stations (STNS = 9) would have a total of 27 cards input for that rotor (3 cards per set x 9 stations).

Tip Vortex Coordinate Overwrite Input

In order to include a more realistic tip vortex geometry than the classical undistorted geometry, a tip vortex coordinate overwrite option is available. This option allows the program operator to input, via cards, the tip filament geometry. This geometry can be obtained from experimental data or analytical results. With this option more realistic near field effects can be obtained in cases where the wake is known to distort significantly from the classical model, and the geometry of the tip vortex is critical to obtaining accurate inflow solutions. The required input format is presented below.

The tip filament wake geometry is defined by inputting the vortex segment end point coordinates in the rotor wake reference system, (hub centered, parallel to the tip path plane and aligned with the free stream velocity). Since the wake geometry is assumed to be periodic with blade spacing, the number of rotor positions is just 360/(B·DPSI). In the program this quantity is called BJTOT. Thus, with the wake input for each blade at all of the rotor positions, the total wake geometry for all azimuthal positions is defined. The wake is input in sets of data where each set is associated with a rotor position (L). Each set is then composed of subsets of data corresponding to each blade at a given rotor position. The format is as follows:

For each subset the first card describes the blade number (IB) and the number of vortex segment endpoints to be input for that blade at that rotor position (NPM). These must be two integer, right adjusted numbers described by the Fortran format 2I5 (Columns 1-5, 6-10). On the following cards the x, y and z coordinates, in that order, for each endpoint are punched,·.

The point input sequence is in the following order. The last point in the wake to be overwritten is input first, the next to last next, and so forth until the point corresponding to the blade segment boundary is input, this being the last point to be input for that filament. This allows the computer to retain all the classical wake points past the overwrite. Thus any portion of the tip filaments may be overwritten. The number of overwrite points for any filament must not exceed the total number associated with the corresponding classical wake. These items are input using a floating point format, eight spaces to an item, nine items to a card (3 segment end points). When this is completed the following blade subsets (ordered first to last) are punched in the same manner.*

* The rotor blades are ordered as follows. Blade one lies at the first azimuthal position (including phasing) and the following blades (2 through B) are defined to exist azimuthally behind the first blade. For example: with a 3-bladed rotor, if blade one is at zero azimuth, blade two is at 240 deg and blade three is at 120 deg.

To complete a set of data (one rotor position), this grouping of
cards is preceeded by a single card describing the particular rotor
position this set is for. A fixed point, right justified format is used,
Fortran format I10 (Columns 1-10). This format is repeated for each rotor
position (ordered first to last) to complete the wake overwrite input.
Figure 6 is a pictoral representation of this input sequence for one rotor.
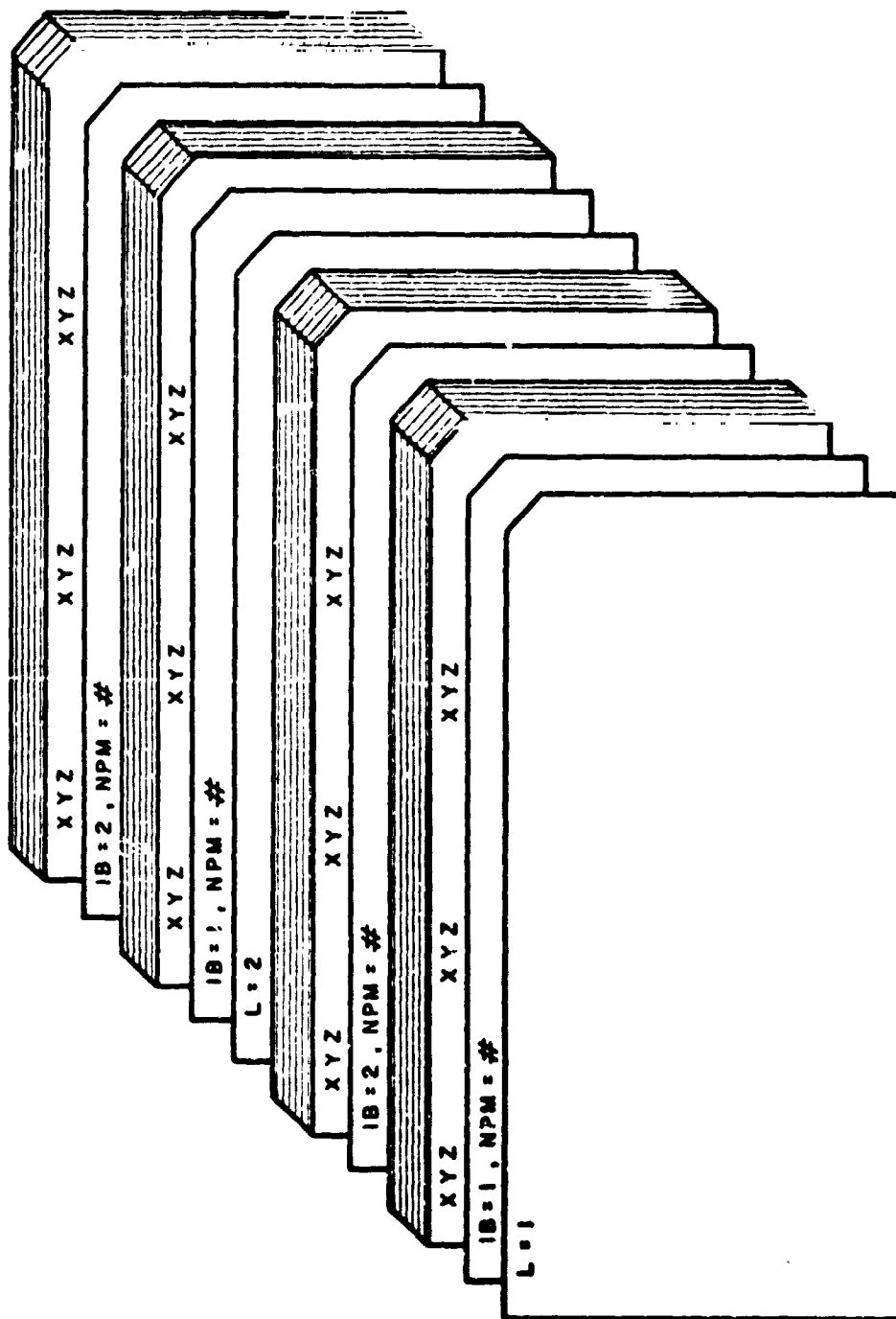
Figure 6. Sample Card Input for Tip Vortex Geometry Overwrite

Summary List of Available Options

In order to group together the available options for use in this program, the following list is presented. All of the items listed are controlled by input items in the basic variable input. Listed are the available option controls and their locations. Details of their use were described in the input instructions.

OPTION	LOCATION	NAME OF OPTION CONTROL
Interpolated induced velocities	39	STNEW
Different types of wakes	186	TYWAKE
Anhedral Tip	191	ANDTIP
Wake truncation	200, 210	TRUNC, TRUNCI
Rollup of filaments into tip filament	190	ROLLUP
Input of W1 (noninduced inflow)	206	W1OPT
Airfoil Characteristics	207	WOPT
Geometric Coefficient print option	208	OPTPO
Matrix Solution print option	209	PRINT
Induced velocity punch option	210	PUNCH
Wake coordinate print option	211	CPOPT
Print option for blade points within vortex core	212	CROPT
Circulation punch option	213	CPUNCH
Program link option	220	OPLINK
Intermediate print option	221	DEBUGP

DESCRIPTION OF PROGRAM OUTPUT

Categories and Sequence of Program Output

The categories of program output which are printed in the following sequence are:

1. Print of Basic Variable Input Data

2. Intermediate Printout (optional)

3. Wake Coordinate Printout (optional)

4. Circulation Matrix Printout (optional)

5. Print of Circulation and Induced Velocity Solutions and Related Parameters

6. Print of Harmonic Coefficients of Induced Velocity

In addition, punched card output of the induced velocity and circulation solutions is optional. A detailed description of the output items included in each of the above categories follows below. A sample computer printout of the output items is presented in a later section of this report.

Print of Basic Variable Input Data

This output is the same data which is input in the Basic Variable Input section via LOADER format. It is printed with a special output format to facilitate the program operator's ability to quickly change variable items without the necessity of using the program documentation once a basic understanding of the program is obtained. Descriptions of any of the items can be found in the input section of this report. The print format for each particular item is as follows. The first output quantity is the location of the item in the loader array. The second quantity is the variable name of the item as used in the program. A brief description of the item and its units follows. The last quantity output is the actual value of the item.

Intermediate Printout (Optional)

When running this program the user may or may not be interested in certain quantities related to the solution of the particular case in hand. In order to keep printout to a minimum, the printout of this information has been made optional. The option control is DEBUCP in location 221 of the basic variable input. The first of these quantities are the rotor blade coordinates in the cartesian coordinate system. These coordinates are listed in tabular form, horizontally as a function of radial station (RS) and vertically as a function of azimuth position (PSI).

The following items are aerodynamic in nature and are local blade element quantities. They use the same output format as noted above, and are output in the following order.

1. In-plane velocity component table, UT (fps).

2. Mach number table, MACH.

3. Airfoil lift curve slope-table AT (C_1/rad).

4. Angle of attack for maximum lift table, ALMAX (deg).

5. Angle of attack for zero lift table, ALO (deg).

6. Total axial noninduced velocity component table, W1 (fps).

7. The product of the lift curve slope and the inplane velocity component table, ACUTAB (ft2/sec).

8. The maximum circulation table, based on stall considerations, CIRCM (ft^2/sec).

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Wake Coordinate Printout (Optional)

If desired, the coordinates of the vortex filament segment endpoints
are printed for each filament string of each blade at each rotor position.
The option control is CPOPT in location 211 of the basic variable input.
The coordinates listed are nondimensionalized by the rotor radius. For
any one filament, the first coordinate set is the last segment endpoint
of the string (i.e., the oldest segment). The last value listed in the
filament segment endpoint on the blade. All points in between are
naturally sequenced in order (i.e., oldest to newest). The coordinate
print is frequently omitted because of the printout page requirements.

Circulation Matrix Printout (Optional)

The formulation of the circulation matrix coefficients was
previously presented in the description associated with Equations 1
through 17. In summary, the geometric coefficients are defined as the
geometric functions in the Biot-Savart relation used to calculate the
velocities induced by the wake and bound vortex segments at the blade.
Since the circulation strengths of all wake segments within a given trailing
vortex filament are assumed periodic with azimuth position for the forward
flight condition, the geometric coefficients of a group of segments within
a filament for the same azimuthal position at the time of generation may
be summed over all revolutions to establish a representative geometric
coefficient for the group (GCTROW). To relate these coefficients to the
respective bound circulations, a difference is computed between the wake
coefficients of the trailing filaments to obtain the geometric coefficients
corresponding to the azimuthally varying bound circulations as related to
the wake structure. To these values are added the effects of the bound
circulations (GCB). The resulting quantities, GCMAT are used to form the
coefficients of the circulation matrix as shown on p.   in Equation 16.
Within the matrix solving subroutines (MILSOP or MILSOP2), the matrix is
normalized by dividing each of these values by the diagonal element. The
option control for printing these circulation matrix coefficients is PRINT
(location 209) in the basic variable input. An option is also provided by
PRINT to output the intermediate circulation solutions at each iteration.
These two options are generally not used because of the lengthy print
requirements. If the circulation matrix coefficients are output, the
matrix row and column is printed for each line of data for reference.
The intermediate circulation solutions are output with it's position
in the column vector. If desired, the GCMAT quantities may be printed.
The option control in the basic variable input is OPTPO (location 208).
When this option is used the output is in the following form. At each
inflow point on the rotor disk the geometric coefficients are listed
(10 to a line). They are ordered according to radial station for each

azimuth with no indication where the break from one azimuth position to another is made. This printout is not in as convenient an output form as the matrix coefficients and is not generally used.

Print of Circulation and Induced Velocity
Solutions and Related Parameters

The blade bound circulation and induced velocity solutions are printed for each radial station and azimuth position. These output items are not optional since they are the desired results of the program operation. Following the circulation and induced velocity printout, the blade angle of attack distribution based on Equation   is printed. A stall indicator table is printed next. In this table, a 0.0 or a 99.99 is printed for each radial station and azimuth position. A 0.0 indicates no stall. A 99.99 indicates that the stall limit (ACURVE, see p.   ) was exceeded and that the circulation at that station was limited to a maximum value in the circulation solution. If used, the interpolated induced velocity distribution is then printed.

Print of Harmonic Coefficients of
Induced Velocity

The induced velocity solutions are harmonically analyzed and the harmonic coefficients, based on a positive Fourier series, are printed. The harmonics are printed for the inflow stations (RS) unless interpolated radial stations (RSNEW) have been requested.

Punched Cards of Induced Velocity
and Circulation Solutions

An option for punched cards of the induced velocity solutions at each blade radial station and azimuth position is available and controlled by PUNCH (location 210) in the basic variable input. An option for punched cards of the harmonic coefficients of induced velocity at each blade radial station is also controlled by PUNCH. An option for punched cards of the circulation solutions is controlled by CPUNCH (location 213).

SPECIAL INPUT AND OPERATING INSTRUCTIONS

This program will allow the use of a wide range of rotor blade geometries. Variable twist blades (both linear and nonlinear) can be used. Variable chord distributions can be used. No restriction on the number of blades is made. The program assumes solution periodically with blade spacing. The choice of DPSI and the number of blades is interdependent since DPSI must be such that the number of rotor positions between blades and the number of blades are compatible (360/B/DPSI = integer). The flapping hinge offset must be inboard of the innermost vortex sheet filament.

Concerning the choice of radial stations for the inflow solutions, careful selection of stations is necessary. Since the inflow stations also define the trailing vortex filament spacing, attention must be given during their selection to the wake model that results. Generally the tip region should contain a larger number of filaments per unit length than the inboard region. This allows a better modeling of the concentration of trailing vorticity in the region of the tip vortex and also gives better resolution of the bound circulation near the tip (this is needed because of the severe loading gradients observed in this region). Standard values which are generally used at UARL for a 9 station case can be obtained from the input description of RS in the basic variable input section of this appendix. The inboard values must be adjusted for different root cutouts of various blades. If an anhedral tip is being used, a maximum of five inflow solution stations is allowed outboard of the start of the anhedral tip section.

When modeling wake rollup in forward flight, careful selection of the number of filaments that rollup into a concentrated tip vortex is also necessary. The selection is based on taking the average of the radial position of peak circulation on the disk and choosing the number of filaments for rollup to be the total of those which are outboard of this average radial position. Since the locations of the peak circulations are not known beforehand an iteration procedure may be necessary. Generally for the stations mentioned above, the 5 outboard filaments are "on the average" outboard of the average radial location of peak circulation.

The blade motion and control parameters should be chosen to be compatible with the wake model used, since these parameters determine to a large degree the rotor thrust, blade loading and other parameters which are directly related to the wake geometry. Generally a separate program is used to compute these parameters for a desired operating condition. With these parameters, other appropriate input, and a wake model, the resulting inflow distribution is computed with this program. This inflow is then used in the program which generated the control parameters values and rerun. If the new control parameters are reasonably close to the required values the wake model and control parameters are compatible. If not, more iterations may be necessary.

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Operation of this program is gene. ally straightforward once a basic understanding of the program input is obtained. However, there is one area where problems may occur. For cases in which vortex elements come within extreme close proximity to blades, large unrealistic geometric coefficients can result. These large values can lead to large off-diagonal terms in the circulation matrix which results in convergence problems in the matrix solution or locally unrealistic solutions. This may generally be avoided by proper selection of the core radius assigned to the vortex filaments. (The velocity induced by vortex element is set to zero for blade points wihtin the vortex core radius). Experimental data indicate tip vortex core radii of approximately one-tenth of the blade chord for helicopter rotors. However, the proper core radius for the inboard filaments representing the vortex sheets is not well defined at this time. Values of one-tenth to three-tenths of the blade chord have generally been used. However, some unrealistic solutions associated with close proximity have resulted in certain instances with the former value.

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